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(57) Abstract

A method and a device which can be used to measure the moisture content and the internal structure of material on a tobacco bale, or of a bulk volume of material such as loose tobacco leaves, by using microwave radiation. A microwave radiation source is located on one side of the tobacco, such as the tobacco bale, and an antenna is located on the opposite side of the bale. The radiation source beam is transmitted through a portion of the bale and is received by the receiving antenna, which then produces a signal. This signal is used to determine the moisture content of that portion of the bale and the mass uniformity of the bale. In addition, the methods and devices described herein can also be used to measure the moisture content of a bulk volume of loose tobacco leaves, for example as these leaves travel through a silo. Also, in a method for analyzing the internal structure of packaged tobacco, the internal structure is analyzed to detect the presence of any foreign objects or matter in packaged tobacco, as well as to confirm the presence of tobacco material throughout the package. The structural data is collected from the received and/or reflected microwaves, which are also analyzed to determine the moisture content. The raw structural data are then analyzed with detection, classification, and/or decision algorithms for analysis of the raw data. Preferably, the data analysis is based on pairs of attenuations and phase shifts obtained by passing microwaves at a plurality of frequencies through the package of tobacco which features foreign matter or objects, collectively termed "foreign components" and/or non-uniformities. This unique method enables achievement of high levels of accuracy and precision in detection and classification of the sample, in general, and of the foreign components and/or non-uniformities, in particular.

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DEVICE AND METHOD FOR NON-INVASIVELY MEASURING AND DETERMINING MOISTURE CONTENT AND DENSITY OF LOOSE AND PACKAGED TOBACCO

FIELD AND BACKGROUND OF THE INVENTION

The present invention relates to a device and method for measuring and determining moisture content and density of tobacco and tobacco products, and in particular for non-invasively measuring and determining moisture content and density of loose and packaged tobacco.

Tobacco plants are cultivated for the main purpose of obtaining tobacco leaves which are used as the principle raw material in manufacturing a diversity of tobacco containing end products. Raw tobacco leaves are bundled, transported and stored in a variety of forms before being used in manufacturing processes. Tobacco manufacturing processes typically involve multiple procedures, including initial processing of loose or packaged raw tobacco leaves, and then using the processed tobacco leaves in formation of various tobacco containing end products. Tobacco end products are also packaged, stored, and transported with respect to distribution and sale throughout the tobacco consuming marketplace.

Hereinafter, the term 'tobacco' refers to any form of either raw or processed tobacco plants, raw or processed tobacco leaves, including tobacco leaves freshly picked from a tobacco plant or dried tobacco leaves, green or other color, and including processed tobacco leaves as an ingredient in tobacco containing end products such as cigarettes, cigars, pipe tobacco, pouch tobacco, chewing tobacco, etc.. Moreover, either raw or processed tobacco may be considered in either a loose or a packaged form, where packaged form of tobacco includes, but is not limited to, tobacco in loosely bound piles, bales, modules, bags, cases, cartons, or boxes. Hereinafter, the term 'bale' refers to any structure in which tobacco material is present in pressed layers and tied with ties wrapped around the structure, and includes, but is not limited to, farmer bales, in which tobacco leaves are bound with ties alone; a case, in which tobacco leaves are placed in crates with wooden or cardboard sides; a hogshead, in which the case has a substantially cylindrical shape; and an oriental bale. Hereinafter, the term 'module' refers to any structure of bound tobacco material, including bales and cases.

Within the sequence encompassing obtaining raw tobacco leaves to supplying the marketplace with tobacco end products, several procedures are dependent upon the moisture content and/or density of tobacco, in either loose or packaged form. If moisture content is too

high. for example, physicochemical properties and characteristics of tobacco tend to change, possibly resulting in decomposition during transportation and storage, even before the tobacco is used in a manufacturing process. If the moisture content is too low, processing and use of tobacco may be problematic. Density of packaged tobacco, related to moisture content of tobacco, for example, can be used as a quality control parameter with respect to tobacco packaging processes, either involving packaging some form of raw tobacco prior to manufacturing tobacco end products, or for packaging tobacco end products prior to distribution and sale in the marketplace.

Tobacco is typically stored in large bales before being processed for manufacturing tobacco end products. Chemical composition of stored tobacco can alter as a result of various reactions involving compounds found in tobacco. Some of these reactions can produce chemicals which are particularly harmful to people who smoke, while other products are detrimental to the taste and shelf life of tobacco products. Indeed, the relevant regulatory authority in each country, such as the FDA (Food and Drug Administration) for the United States of America, frequently requests maximum levels of the harmful chemical compounds. If the concentration of one or more of these components exceeds this limit, the regulatory authority may not permit the tobacco product to be sold within the country. The rate and extent of these reactions may be altered by the moisture content of the tobacco. Therefore, the tobacco industry must process the tobacco within a relatively narrow range of moisture values, in order to comply with these regulations and in order to maintain the quality of the tobacco. Thus, clearly the concentration of these components within the tobacco must be monitored, and if possible the tobacco must be processed substantially before such components increase to potentially harmful levels.

Since rate and extent of tobacco alteration are influenced by moisture content of tobacco, it is desirable to measurement moisture content of tobacco, in order to optimally store and process tobacco. Unfortunately, currently available methods for measurement of moisture content of tobacco involve the removal of samples from tobacco bales, followed by separate, off-site, determination of moisture content of the tobacco samples. Such sampling can be very inaccurate, since moisture content of the tobacco may vary widely throughout the bale, in addition to varying from bale to bale, thereby yielding misleading results. Measurement of moisture content of loose tobacco leaves is also important, yet is also difficult to determine by off-site sampling of small portions of tobacco material. Preferably, bulk volumes of tobacco material would be measured as tobacco leaves pass through a silo, for example on a conveyor

belt, rather than by separate sampling of the material. Thus, currently available methods for measuring the moisture content of both tobacco bales and bulk volumes of loose leaves have significant drawbacks.

A far more useful method for determining the moisture content of tobacco would involve the measurement of the moisture content throughout the bale, such that a more accurate moisture measurement could be made. Such a method would also preferably preserve the tobacco material, such that the tobacco would not be destroyed during the process of measuring the moisture content. Furthermore, regulation of the moisture content would enable control in levels of the various chemical compounds produced as a result of the previously described chemical processes. Thus, an accurate determination of moisture content of tobacco is necessary for proper storage and manufacture of tobacco products.

In addition to influencing measurement of moisture content of raw or processed, loose or packaged tobacco, measuring density of packaged, raw or processed, tobacco can be very useful for monitoring and quality control of the internal structure of such packaged tobacco. Packaged tobacco may contain foreign components and/or non-uniformities which can affect both the accuracy of measuring moisture content and downstream processing of tobacco. A practical example of a non-uniformity in internal structure of packaged tobacco is, at a cigarette or cigar manufacturing facility, where a crate contains an off-spec number of cigarette or cigar cartons, and similarly, where a carton contains an off-spec number of cigarette or cigar packs. Ideally, a non-invasive, non-damaging method and device would be used for measuring density and determining internal structure of such packaged tobacco, without physically or chemically altering the tobacco or the tobacco packaging. Unfortunately, such a device and method are currently not available.

There is thus a widely recognized need for, and it would be highly advantageous to have, a device and method for non-invasively measuring and determining moisture content and density of raw or processed, loose or packaged, tobacco.

SUMMARY OF THE INVENTION

According to the present invention there is provided a method of determining a moisture content of tobacco material, the method comprising the steps of: (a) transmitting a plurality of microwaves substantially through at least a portion of the material, such that the microwaves are transmitted microwaves; (b) receiving the transmitted microwaves such that the microwaves are

received microwaves; (c) determining an attenuation from the received microwaves; (d) using at least one empirical factor selected from the group consisting of weight of the material, temperature of the material, structure of the material and type of the tobacco material to correct the attenuation, producing a corrected attenuation; and (e) calculating the moisture content of the tobacco material from the corrected attenuation. Preferably, the step of determining the attenuation further comprises the step of determining a phase shift from the received microwaves.

According to preferred embodiments of the present invention, the step of determining the attenuation further comprises the step of: (i) repeating steps (a) to (c) for at least a portion of the material on the bale, such that a plurality of phase shifts and a plurality of attenuations are obtained, and such that a plurality of corrected phase shifts are produced according to the plurality of phase shifts.

Preferably, the method further comprises the step of: (ii) determining a density of the material from the phase shifts; and (iii) calculating a final moisture content of the material from the density and from the raw moisture content.

Alternatively and preferably, the material features an internal structure and an irregularity of the density of the internal structure is calculated by comparing one of the plurality of phase shifts to a previous value of the phase shifts, such that the irregularity is detected if one of the plurality of phase shifts differs from the previous value. More preferably, the irregularity of the density of the internal structure indicates that the material has been processed unevenly, which can result in problems during the process of fermentation due to uneven moisture content of the material, thereby affecting the overall quality of the tobacco.

According to other preferred embodiments of the present invention, a first phase shift is determined for microwave radiation of a first frequency F_1, and a second phase shift is determined for microwave radiation of a second frequency F_2, the first phase shift being corrected to form a first measured phase shift according to the equation:

$$Ph_{F_1} = \frac{\Delta Ph(F_2) - \Delta Ph(F_1)}{F_2 - F_1} F_1$$

wherein Ph_{F_1} is the measured phase shift for the first frequency F_1; and $\Delta Ph(F_1)$ and $\Delta Ph(F_2)$ are the phase shifts for F_1 and F_2; and wherein a first corrected phase shift is formed according to the following steps:

(i) $Ph_{F_1} / 360 = X_1$; and

(ii) $(\mathrm{mod}(X_1) * 360) + \Delta Ph(F_1) = P_{true}$;

such that P_{true} is the first corrected phase shift. Preferably, the moisture content is determined according to a ratio of the attenuation and the corrected phase shift.

More preferably, an empirical curve of a relation between the ratio and the moisture content is provided, such that the moisture content is determined according to the ratio by using the empirical curve.

Preferably, the tobacco material is contained in a module.

More preferably, the at least one empirical factor is a plurality of empirical factors selected from the group consisting of weight of the module, type of the material, structure of the module, location of the module relative to the plurality of microwaves and temperature, and the factors are stored in a database.

Most preferably, the corrected attenuations and the phase shifts are further corrected by removing attenuations and phase shifts produced after the plurality of microwaves passes through an edge of the module, such that a first portion of the plurality of microwaves passes through the portion of the module and a second portion of the plurality of microwaves substantially does not pass through the portion of the module.

Preferably, the step of determining the density includes detecting a defect in the material, the defect being selected from the group consisting of irregular moisture distribution within an interior of the material and presence of a foreign body inside the material.

According to another embodiment of the present invention, there is provided a method for determining a moisture content of tobacco material, the method comprising the steps of: (a) transmitting a plurality of microwaves substantially through at least a portion of the material, such that the microwaves are transmitted microwaves; (b) receiving the transmitted microwaves such that the microwaves are received microwaves; (c) determining an attenuation from the received microwaves; (d) determining a phase shift from the received microwaves; and (e) calculating the moisture content of the tobacco material from a ratio of the attenuation and the phase shift.

Preferably, the step of calculating the moisture content further comprises the steps of: (i) providing an empirical curve of a relation between the ratio and the moisture content; and (ii) determining the moisture content according to the ratio by using the empirical curve.

More preferably, the step of determining the attenuation further comprises the step of: (i) using at least one empirical factor selected from the group consisting of weight of the material, temperature of the material, structure of the material and type of the tobacco material to correct the attenuation, producing a corrected attenuation.

Most preferably, the step of determining the phase shift further comprises the steps of: (i) determining a first phase shift for microwave radiation of a first frequency F_1; (ii) determining a second phase shift for microwave radiation of a second frequency F_2; and (iii) correcting the first phase shift to form a first corrected phase shift according to the equation:

$$Ph_{F_1} = \frac{\Delta Ph(F_2) - \Delta Ph(F_1)}{F_2 - F_1} F_1$$

wherein Ph_{F_1} is the corrected phase shift for the first frequency F_1; and $\Delta Ph(F_1)$ and $\Delta Ph(F_2)$ are the phase shifts for F_1 and F_2.

According to yet another embodiment of the present invention, there is provided a method for determining a moisture content of tobacco material, the method comprising the steps of: (a) transmitting a plurality of microwaves of a plurality of frequencies substantially through a portion of the material, the microwaves of each of the plurality of frequencies being transmitted sequentially such that the microwaves are transmitted microwaves of a particular frequency; (b) receiving the transmitted microwaves of the particular frequency such that the microwaves are received microwaves of the particular frequency and such that the transmitted microwaves from the plurality of frequencies are received; (c) determining an attenuation from the received microwaves of each of the particular frequencies, such that a plurality of attenuations is determined; (d) determining a phase shift from the received microwaves of each of the particular frequencies, such that a plurality of phase shifts is determined; (e) correcting each of the plurality of phase shifts according to the plurality of phase shifts, such that first phase shift is determined for microwave radiation of a first frequency F_1, and a second phase shift is determined for microwave radiation of a second frequency F_2, the first phase shift being corrected to form a first corrected phase shift according to the equation:

$$Ph_{F_1} = \frac{\Delta Ph(F_2) - \Delta Ph(F_1)}{F_2 - F_1} F_1$$

wherein Ph_{F_1} is the corrected phase shift for the first frequency F_1; and $\Delta Ph(F_1)$ and $\Delta Ph(F_2)$ are the phase shifts for F_1 and F_2; and (f) determining the moisture content according to a ratio of the corrected phase shift and the attenuation.

According to still another embodiment of the present invention, there is provided a method of analyzing packaged tobacco to determine an internal structure of the packaged tobacco, the method comprising the steps of: (a) performing a calibration procedure on a plurality of calibration samples of the packaged tobacco to determine a plurality of target types, the calibration procedure including a step of transmitting microwaves through at least a portion

of each of the plurality of calibration samples; (b) transmitting a plurality of microwaves substantially to at least a portion of the packaged tobacco , such that the microwaves are transmitted microwaves; (c) receiving the transmitted microwaves such that the microwaves are received microwaves, the received microwaves include reflected microwaves; (d) determining a plurality of attenuations from the received microwaves; (e) determining a plurality of phase shifts from the received microwaves; (f) calculating a plurality of at least one of a moisture value and a density value of the package of the packaged tobacco from at least one of the plurality of the attenuations and the plurality of the phase shifts; and (g) analyzing the plurality of the moisture and the density values to determine at least one target in the packaged tobacco, according to the target types determined from the calibration procedure, the at least one target showing at least a portion of the internal structure of the packaged tobacco.

According to yet another embodiment of the present invention, there is provided a method of analyzing packaged tobacco to detect a presence of at least one characteristic selected from the group consisting of a foreign component and a non-uniformity of the material, by transmitting microwaves through at least a portion of the packaged tobacco, the method comprising the steps of: (a) performing a calibration procedure on a plurality of calibration samples of the packaged tobacco to determine a plurality of target types, the calibration procedure including a step of transmitting microwaves through at least a portion of each of the plurality of calibration samples; (b) acquiring a plurality of at least one of a moisture value and a density value of the packaged tobacco by analyzing the microwaves transmitted through the packaged tobacco, the microwaves include reflected microwaves ; and (c) analyzing the plurality of values to detect at least one potential target, according to the target types from the calibration procedure.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIGS. 1A and 1B are illustrative examples of modules whose moisture can be measured by the present invention;

FIG. 2 is a block diagram illustrating one embodiment of the present invention;

FIG. 3 shows an example of a calibration curve used for calculating the moisture content of the module according to the present invention;

FIGS. 4A and 4B show a phase region curve of a preferred embodiment of the present

invention;

FIGS. 5A-5F illustrate the relationship between the direction of the electrical field of the source beam relative to the module and the attenuation and phase shift of the antenna signal;

FIG. 6 illustrates a truck for conveying the device of Figure 2;

FIGS. 7A-7C illustrate another embodiment of the present invention;

FIG. 8 illustrates the behavior of the antenna signal of the embodiment of Figures 7A and 7B;

FIG. 9 is a flow chart of the method of calculating the moisture content of the tobacco material;

FIG. 10 is a flow chart of another method for calculating the moisture content of the tobacco material;

FIGS. 11A-11D show illustrative experimental results using the method of the present invention.

FIG. 12 shows a second exemplary embodiment of a device which can be used with the method of the present invention;

FIGS. 13A-13B show flowcharts of another preferred and exemplary method according to the present invention for detecting the presence of foreign components and/or non-uniformities in the package of tobacco;

FIG. 14 shows the target classification process according to the present invention from Figures 13A-B in more detail;

FIG. 15 shows actual empirical data for the detection of a non-uniformity in the internal structure of a bale of tobacco;

FIGS. 16A-16C show other moisture content and/or density classifiable patterns recognizable in bales of tobacco;

FIG. 17 illustrates density related detection and pattern recognition of tobacco objects missing from a carton having a known number of discrete tobacco objects; and

FIG. 18 illustrates applicability of pattern recognition data processing of microwave measurements involving acquisition of both transmitted and reflected microwave signals.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is of a device and method for non-invasively measuring and determining moisture content and density of loose or packaged tobacco. The tobacco may be in any form of either raw or processed tobacco plants, tobacco leaves, including tobacco leaves

freshly picked from a tobacco plant or dried tobacco leaves, green or other color, and including processed tobacco leaves as an ingredient in tobacco containing end products such as cigarettes, cigars, pipe tobacco, pouch tobacco, chewing tobacco, etc.. Moreover, either raw or processed tobacco may be in either a loose or a packaged form, where packaged form of tobacco includes, but is not limited to, tobacco in loosely bound piles, bales, modules, bags, cases, cartons, or boxes.

The present invention is based on subjecting any of the above described forms of tobacco to microwave radiation, where the microwave radiation is of variable frequency. Typically, a microwave radiation source is located on one side of the tobacco, such as the tobacco bale, and an antenna is located on the opposite side of the bale. The radiation source beam is transmitted through a portion of the bale and is received by the receiving antenna, which then produces a signal. Microwave signal parameters such as attenuation and phase shift are used to measure and determine moisture content of that portion of the bale, mass uniformity of the bale, and density of the bale. A method for performing such moisture and density measurements is disclosed in U.S. Patent No. 5,621,330, referenced herein as if incorporated in full. Additional aspects of such a method are also disclosed in U.S. Patent Application Nos. 08/777,872 and 08/974,983, also referenced herein as if incorporated in full. In addition, the methods and devices described herein can also be used to measure the moisture content of a bulk volume of loose tobacco leaves, for example as these leaves travel through a silo.

Based on measurement and determination of density of packaged tobacco, internal structure of packaged tobacco is analyzed to detect the presence of any foreign components and/or non-uniformities, as well as to confirm the presence of tobacco material throughout the package.

Raw data of the microwave measurements, including attenuation and phase shift, are used for determination of moisture content and density, values of which are ultimately translated into useful information relating to characteristics and internal structure of tobacco. Calibration measurements are also performed on standard, well characterized, calibration samples of various forms of tobacco, according to the actual application involving raw or processed, loose or packaged tobacco, for the purpose of comparing to microwave measurements of actual tobacco samples. Results of calibration measurements are correlated with respect to selected known features of tobacco samples. Results of calibration data correlations are further classified according to distinct and recognizable patterns. Classified patterns are, in turn, very useful for interpreting raw data obtained from microwave measurements of actual tobacco samples, in

order to detect and identify pre-determined features pertinent to monitoring or quality control of a tobacco related manufacturing process.

In the present invention, raw data are analyzed, in part, by using pattern detection, classification, and/or decision algorithms. Examples of specific pattern detection, classification, and/or decision algorithms suitable for data analysis in the method of the present invention are fully described in U.S. Patent No. 5,880,830, issued to Schechter, and in pending U.S. Patent Application No. 09/146,361, and references cited therein, which are incorporated by reference for all purposes as if fully set forth herein. Preferably, in the present invention, data analysis is based on acquiring pairs of attenuations and phase shifts by passing microwaves at a plurality of frequencies through a package of tobacco featuring foreign matter or objects, collectively termed 'foreign components' and/or non-uniformities. This unique method enables achievement of high levels of accuracy and precision in detection and classification of the sample, in general, and of foreign components and/or non-uniformities, in particular.

The principles and operation of a device and a method according to the present invention may be better understood with reference to the drawings and the accompanying description.

Referring now to the drawings, Figures 1A and 1B are illustrative examples of modules whose moisture can be measured by the present invention. Figure 1A shows a module **10** which is a bale of tobacco **12**. Bale **12** consists of pressed layers of tobacco material **14**, optionally held together with at least one tie bar **16**. Tie bar **16** can be made of plastic or metal. For the purposes of measuring the moisture content of bale **12**, bale **12** can be divided into at least one, and preferably a plurality, of areas **17**. Each area **17** includes at least one measurement point **18**, and preferably a plurality of measurement points **18**. At each measurement point **18**, the moisture content of that portion of bale **12** is determined (see Figure 2 below).

Figure 1B illustrates a module **10** which is a case of tobacco **20**, for example used for storing tobacco. Case **20** does not have defined layers, unlike bale **12**. However, case **20** can also be divided into at least one, and preferably a plurality, of areas **22**. Furthermore, each area **22** can also be subdivided into at least one, and preferably a plurality, of measurement points **24**. At each measurement point **24**, the moisture content of that portion of case **20** is determined (see Figure 2 below).

For illustrative purposes only, description of the device and method of the present invention is limited to measurement of moisture content and density of tobacco leaves in modules such as bales, it being understood that this is not meant to be limiting in any way. These moisture and density measurements can be performed on tobacco leaves in substantially

any structure, including bulk volumes of loose leaves. The type of structure of the tobacco material depends partly upon the stage of the processing of the tobacco. Briefly, tobacco leaves are loose, bulk volumes of material after being harvested and threshed. Tobacco leaves are then bound into bales, after which the primary processing is performed. The primary processing stage includes cutting the tobacco. The cut tobacco is typically stored in some type of case, such as a wooden box. The secondary processing stage is then performed, in which tobacco products such as cigarettes are manufactured. Thus, the method of the present invention can be used for the measurement of moisture content of tobacco, and for measurement of density of packaged tobacco, in substantially any stage of the processing, although specific reference is made herein to modules and bales.

Figure 2 shows a device according to one embodiment of the present invention. Device **26** includes a microwave radiation source **28**, shown on one side of module **10**. Microwave radiation source **28** preferably includes at least one source antenna **30** for transmitting a source beam **32**. Source beam **32** is directed through module **10**, and passes out of module **10** as an exit beam **34**. While traveling through module **10**, source beam **32** may also be reflected by packaging material which reflects microwave radiation. Such packaging material could include a metal, for example, aluminum wrapping used for assisting in maintaining freshness of tobacco. Thus, an exit beam **34** includes microwaves transmitted through the tobacco material in addition to any reflected microwaves exiting module **10**. Exit beam **34** is received by at least one receiving antenna **36**. Receiving antenna **36** is located on a substantially opposing side of module **10** relative to source antenna **30**.

After receiving antenna **36** has received exit beam **34**, receiving antenna **36** produces an antenna signal **38**. Antenna signal **38** then goes to an attenuation unit **40**. Attenuation unit **40** includes an attenuation measurer **42**, which measures the attenuation of antenna signal **38**. As source beam **32** passes through module **10**, source beam **32** is attenuated. The extent of this attenuation is determined by the elementary mass, which is the mass of the material of module **10** encountered by source beam **32**, and by the moisture content of the material of module **10** encountered by source beam **32**. Thus, attenuation measurer **42** is actually measuring the extent to which source beam **32** is attenuated by passing through module **10**.

At least a part of antenna signal **38** also goes to a phase shift determiner **44**, which determines the phase shift of antenna signal **38**. This phase shift is actually the phase shift of source beam **32** passing through module **10**, so that the phase shift is the difference between the phase of source beam **32** and the phase of exit beam **34**. The attenuation and the phase shift are

determined according to the following equations:

$$A = 8.68\ \alpha l$$

l being length of module **10**, α being the attenuation factor for module **10**.

$$P = (\beta - \beta_0)l$$

β and β_0 being phase factors for module **10** and air, respectively.

The attenuation and the phase shift of antenna signal **38** are then used by a moisture determiner **46** to determine the moisture content of module **10**.

Moisture determiner **46** uses the following equations to determine the moisture content of module **10**. In these equations, A is attenuation, P is phase shift, W is moisture content, and M is the elementary mass of module **10**. Equations 1 and 2 are integrated to produce equations 3 and 4. The moisture content, W, is then calculated.

$$dA = \frac{\partial A}{\partial W} dW + \frac{\partial A}{\partial m} dm$$

$$dP = \frac{\partial P}{\partial W} dW + \frac{\partial P}{\partial m} dm$$

$$A = \frac{\partial A}{\partial W} W + \frac{\partial A}{\partial m} m$$

$$P = \frac{\partial P}{\partial W} W + \frac{\partial P}{\partial m} m$$

A number of optional features can be added to device **26** in order to increase the accuracy of moisture measurements. Preferably, attenuation unit **40** includes an attenuator **48**. The function of attenuator **48** is to attenuate antenna signal **38**, so that antenna signal **38** becomes an attenuated antenna signal **50**. A coupler **52** then splits attenuated antenna signal **38** into two portions. A first portion of attenuated antenna signal **50** goes to phase shift determiner **44**. A second portion of attenuated antenna signal **50** preferably goes to attenuation measurer **42**. Attenuation measurer **42** preferably determines the difference between the amplitude of attenuated antenna signal **50** and the amplitude of a constant reference signal **54**. The difference between these two amplitudes determines the extent to which attenuator **48** attenuates antenna signal **38**, so that the attenuation of antenna signal **38** is kept substantially constant. Such constancy is required for the proper operation of phase shift determiner **44** (see below).

As noted above, phase shift determiner **44** determines the difference, or phase shift,

between the phase of source beam **32** and the phase of exit beam **34**. Phase-shift determiner **44** preferably includes a mixer **56**, which outputs a signal which is proportional to the phase shift between source beam **32** and exit beam **34**, as represented by antenna signal **38**. In order for mixer **56** to receive a portion of source beam **32**, microwave radiation source **28** preferably includes a second coupler **58**, for splitting source beam **32** into two portions. A first portion of source beam **32** is directed through module **10** as described above. A second portion of source beam **32** is directed to mixer **56**.

Phase shift determiner **44** preferably also includes a signal phase shift measurer **60**. Signal phase shift measurer **60** measures the phase shift between source beam **32** and exit beam **34** from the signal output by mixer **56**. In order to obtain the most accurate moisture content measurements, phase shift measurer **60** can optionally include a number of features designed to compensate for inaccuracies in the measurement of the phase shift. These features include a raw phase shift measurer **62**, which determines the raw phase shift. Next, a phase region determiner **64** determines the phase region of the raw phase shift from the attenuation of antenna signal **38** and produces a corrected phase shift. As measured directly from source beam **32** and exit beam **34**, as represented by antenna signal **38**, the phase shift can only vary from 0 to 2π. However, the correct phase actually lies between $2\pi(n-1)$ and $2\pi n$, which can be from 0 to 2π, but which could also be from 4π to 6π, for example. Thus, the phase region, or the value of n, must be determined. Such a determination is made using an empirical phase region curve, as shown in Figure 4 below, which relates the attenuation of antenna signal **38** to the phase region. The correct phase shift is then given to moisture determiner **46**.

In order for the phase shift measurement to be accurate, the attenuation of antenna signal **38** must be kept substantially constant. Otherwise, the comparison between source beam **32** and antenna signal **38** will be artificially altered by the attenuation of antenna signal **38**.

As noted above, once the phase shift and the attenuation have been measured, moisture determiner **46** determines the moisture content of module **10**. Moisture determiner **46** preferably includes a temperature sensor **66** for measuring the temperature of module **10**. The type of module **10** is preferably input into moisture determiner **46** by a module type input **68**. The type of module **10** is determined by the type of tobacco material in module **10**, and by the form of module **10**: for example, bale **12** or case **20**. Finally, moisture determiner **46** preferably includes a normalizer **70**. Normalizer **70** preferably includes an empirical function **72**. Empirical function **72** determines the moisture content of module **10** from the temperature and type of module **10**, and from the attenuation and phase shift calculated above.

The above description has treated the measurement of the moisture content of module **10** as though a single moisture measurement was made. However, preferably a plurality of such measurements are made and averaged by an averager **74**. As described in Figure 1, bale **12** can be divided into preferably a plurality of areas **17**. Each area **17** is preferably subdivided into a plurality of measurement points **18**. At each measurement point **18**, the moisture content of that portion of bale **12** is determined according to the above description, so that a plurality of measurements are made and averaged by averager **74**. A similar argument can be made for case **20**, areas **22** and measurement points **24**. These averaged measurements are then preferably compared to a calibration curve, of the type shown in Figure 3, in order to obtain the moisture content of module **10**. Optionally, in order to facilitate such multiple measurements, device **26** can include a conveyor, such as a conveyor belt (not shown) or a truck (not shown, see Figure 6) to convey bale **12** between microwave radiation source **28** and receiving antenna **36**.

Optionally, microwave radiation source **28** can also include a second source antenna **76**. Also optionally, device **26** can also include a second receiving antenna **78**. Optionally, an oscillator **80** controls a first switch **82** and a second switch **84**. These optional features are used to measure the moisture content of module **10** in two parts when module **10** is too tall for a single measurement. First, oscillator **80** flips first switch **82** so that first source antenna **30** directs source beam **32**, and second switch **84** so that first receiving antenna **36** produces antenna signal **38**. This particular configuration is shown in Figure 2, and is used to measure the moisture content of the lower portion of module **10**. Next, oscillator **80** flips first switch **82** so that second source antenna **78** directs source beam **32**. Oscillator **80** also flips second switch **84** so that second receiving antenna **78** produces antenna signal **38**. Now, the moisture content of the upper portion of module **10** is measured.

Microwave radiation source **28** can also optionally include a number of features which are designed to maximize the sensitivity of moisture content measurements, by manipulating the direction of the electric field density of source beam **32** (see also Figures 5A-5F). Microwave radiation source **28** can include an electric field director **86**. Electric field director **86** determines a direction of the electric field density of source beam **32** relative to module **10**, such that the direction of the electric field density partially determines the magnitude of attenuation and magnitude of the phase shift. If module **10** has layers **14** (not shown), substantially the maximum attenuation and substantially the maximum phase shift of antenna signal **38** is obtained when the electric field density is substantially perpendicular to layers **14** (not shown) of module **10**. When the electric field density is substantially parallel to layers **14** (not shown) of

module **10**, substantially the minimum attenuation and the minimum phase shift of antenna signal **38** is obtained. Even if module **10** does not have layers **14**, changing the direction of the electric field density will still alter the attenuation and phase shift of antenna signal **38**, according to the orientation of the material being measured relative to the electric field density. Electric field director **86** determines the direction of the electric field density according to feedback from attenuation measurer **42**. Thus, if the attenuation of antenna signal **38** is low, electric field director **86** can change the direction of the electric field density in order to compensate. Clearly, this has obvious advantages in maximizing the sensitivity and accuracy of moisture content and density measurements.

Figure 3 shows an illustrative example of a calibration curve **88**, showing the relationship between attenuation, in dB, on the Y-axis, and moisture content, as a percentage, on the X-axis. Each calibration curve **88** is empirically determined for each type of module **10** (for example bale or case), and for each type of tobacco material. The moisture content of module **10** is then determined from calibration curve **88**. A more complete description of these curves and their derivation can be found in "Theoretical and Experimental Investigation of Microwave Moisture Measurement of Materials" by A. Greenwald, *FAN*, Uzbekistan, 1982.

Figure 4A shows a graph of a phase region curve **90** as mentioned above. Phase region curve **90** is an empirical curve of the attenuation of antenna signal **38** on the X-axis, and the phase region on the Y-axis. As an example, if the attenuation is equal to A_1, phase region curve **90** shows that the phase region lies between 0 and 2p. Different phase region curves must be determined for each material and type of module **10**.

In order to use this curve, the attenuation and phase shift of antenna signal **38** are preferably measured as module **10** is conveyed between source antenna **30** and receiving antenna **36**. For example, a first measurement could be made before the leading edge of module **10** enters the region between source antenna **30** and receiving antenna **36**, a second measurement could be made as the leading edge of module **10** enters that region, and a third measurement could be made when module **10** is aligned between source antenna **30** and receiving antenna **36**. The relationship between these multiple measurements and the phase region is shown in Figure 4B. At the top is a diagram of module **10** being conveyed between source antenna **30** and receiving antenna **36**. At the bottom is a graph of the relationship between the increasing attenuation as module **10** becomes aligned between source antenna **30** and receiving antenna **36**, and the phase shift, which is based upon empirical phase region curve **90** of Figure 4A. As the phase shift cycles between $0\text{-}2\pi$ while module **10** is conveyed between source antenna **30** and receiving

antenna **36**, the number of cycles can be counted and the phase region can be determined.

Figures 5A-5F illustrate the relationship between the direction of the electric field density of the source beam relative to the module and the attenuation and phase shift of the antenna signal. Figure 5A shows an electric field density **92** and a magnetic field density **94**. Electric field density **92** is perpendicular to layers **14** of module **10**. In Figure 5B, electric field density **92** has been rotated by about 45 degrees. In Figure 5C, electric field density **92** has been rotated by about 90 degrees, relative to Figure 5A. Now electric field density **92** is parallel to layers **14** of module **10**. Figures 5D-5F show the effect of these shifts in the direction of electric field density **92** on attenuation **96** and phase shift **98** of antenna signal **38**. In Figure 5D, both attenuation **96** and phase shift **98** of antenna signal **38** are at substantially a minimum level, because electric field density **92** is perpendicular to layers **14**, as shown in Figure 5A. In Figure 5E, both attenuation **96** and phase shift **98** of antenna signal **38** have increased, due to the rotation of electric field density **92** as shown in Figure 5B. Finally, in Figure 5F, both attenuation **96** and phase shift **98** of antenna signal **38** are at substantially a maximum level, because electric field density **92** is parallel to layers **14**, as shown in Figure 5C.

Optionally, device **26** can be mounted on a truck **100**, as shown in Figure 6. Microwave radiation source **28** and receiving antenna **36** are both mounted on truck **100**. Truck **100** then moves past module **10**, so that module **10** passes between microwave radiation source **28** and receiving antenna **36**. In this manner, a plurality of moisture measurements of module **10** can be made and averaged, as described above.

Figures 7A-7C illustrate another exemplary and preferred embodiment of the present invention. Figure 7A is a schematic illustration of another preferred embodiment of device **26**, similar to the one shown in Figure 2, except that receiving antenna **36** is preferably a circularly polarized antenna. Furthermore, a conveyor **102**, such as a conveyor belt, moves module **10**, shown here as bale **12**, between source of microwave radiation **28** and receiving antenna **36**, such that source beam **32** passes through a portion of bale **12**, and exits bale **12** as an exit beam **34**. Since conveyor **102** is moving module **10**, source beam **32** can pass through a plurality of portions of bale **12**. Thus, if there are i such portions along bale **12**, i moisture measurements can be made. Exit beam **34** is received by receiving antenna **36**, which then produces an antenna signal **38**.

In this embodiment, antenna signal **38** is then examined by a bale alignment determiner **104**. Bale alignment determiner **104** then determines the alignment of bale **12** relative to source beam **32** and receiving antenna **36**. Bale alignment determiner **104** includes a leading edge

transition determiner **106**, an interval timer **108** and a trailing edge transition determiner **110**. Leading edge transition determiner **106** detects when a leading edge of bale **12** has passed radiation source **28**, and produces a leading edge transition signal. Interval timer **108** receives the leading edge transition signal and produces an alignment signal, such that alignment signal is produced when bale **12** is correctly aligned between microwave radiation source **28** and receiving antenna **36**. Trailing edge transition determiner **110** determines when the trailing edge of bale **12** passes microwave radiation source **28**, and produces a trailing edge transition signal.

A moisture determiner **112** then determines the moisture content of bale **12** from the alignment signal. Moisture determiner **112** includes a background moisture content measurer **114**, which measures the background moisture content of antenna signal **38** after receiving the trailing edge transition signal. This background moisture content includes both the ambient moisture content, from source beam **32** passing through the air, and artifacts caused by device **26** itself, such as misalignment of source beam **32** relative to bale **12** and movement of receiving antenna **36** from the correct position relative to bale **12**. Moisture determiner **112** also includes a filter **116** for producing a corrected signal by removing the background moisture content from the alignment signal.

Preferably, moisture determiner **112** also includes a tie bar suppressor **118**. If source beam **32** contacts a tie bar **16** as source beam **32** goes through bale **12**, antenna signal **38** can be affected, potentially resulting in an incorrect moisture measurement. Tie bar suppressor **118** removes any such effects from the corrected signal, and produces a further corrected signal. Preferably, this corrected signal then goes to a normalizer **120**. Normalizer **120** compensates for effects caused by temperature, mass and length of bale **12**, thus normalizing the corrected signal. Such normalization is performed by the following equations:

W_i = the i^{th} moisture measurement in the channel,

W_0 = the nominal mass of the bale » 250 Kg,

W_c = the actual measured mass of the bale,

T_o = the base temperature of the tobacco material (35°C) and

T_c = the temperature of the tobacco material in the current slice,

α = empirical factor compensating for the temperature of the material,

it may be shown that:

$$W'_i = \frac{T_o - T_c}{\alpha} + W_i$$

$$W_{x_i}'' = W_{x_i}'\left(\frac{W_o}{W_c}\right)$$

$$W_{y_i}'' = W_{y_i}'\left(\frac{W_o}{W_c}\right)$$

$$W_{x_i}''' = W_{x_i}'' F(size, shape)$$

The function of (size, shape) is an empirically determined function for compensating for the size and shape of the tobacco material, for example as a bale.

Finally, the normalized signal preferably goes to a mean moisture unit **122**, which determines the moisture content of bale **12**. Preferably, mean moisture unit **122** averages the moisture content of bale **12** over all *i* measurements of *i* portions of bale **12**.

Receiving antenna **36** can optionally include an amplitude determiner **124** and an attenuation determiner **126**. Amplitude determiner **124** determines an amplitude of exit beam **34**. Attenuation determiner **126** then produces an attenuated signal, by determining an attenuation of exit beam **34** from the amplitude of exit beam **34**. The attenuated antenna signal is then processed in a similar fashion as antenna signal **38**.

In the preferred embodiment shown in Figure 7B, source beam **32** is circularly polarized, and exit beam **34** has two mutually orthogonal components. One of these components is in the direction of the X-axis, and one component is in the direction of the Y-axis. For convenience, Figure 7C shows a partial illustration of device **26** according to Figure 7B, with X-, Y- and Z-axes illustrated.

Referring back to Figure 7B, each component is received by one of two linearly polarized microwave receiving antennas **128** and **130**, respectively. Each mutually orthogonal component is separately processed, similar to the above description in Figure 7A, so that there are two bale alignment determiners **104** and **132**. Moisture determiner **112** has two filters **116** and **134** for removing the background moisture component and producing a corrected signal. Preferably, two digital samplers **136** and **138** then produce a digitized signal from each component of the corrected signal. There is also preferably a component moisture computer **140** which then computes a moisture content of each mutually orthogonal component of the digitized signal.

Preferably, moisture determiner **112** also has a ratio determination unit **142** for determining a ratio of each of the moisture contents produced by component moisture computer **140**, according to the following equations:

$$W_{ix(meas)} = W_{ix}\cos\beta + W_{iy}\sin\beta$$

$$W_{iy(meas)} = W_{iy} \sin\beta + W_{ix} \cos\beta$$

$$K = \frac{W_{ix}}{W_{iy}}$$

where:

$W_{i_{x(meas)}}$ = measured moisture content in the X direction for the i^{th} area,

$W_{i_{y(meas)}}$ = measured moisture content in the Y direction for the i^{th} area,

W_{i_x} = maximum moisture content of the i^{th} area in the X-direction,

W_{i_y} = maximum moisture content of the i^{th} area in the Y-direction,

β = the angle of inclination of the layers to the X-direction,

K = the ratio of the maximum moisture values in the X and Y directions, and

α_i = the measured ratio $W_{i_{x(meas)}} : W_{i_{y(meas)}}$

A comparator **144** then compares the ratio with the predetermined constant *K*, which is obtained when layers in bale **12** are substantially parallel. If the ratio is substantially equal to *K*, a parallel layer moisture determiner **146** determines the moisture content of bale **12**. Otherwise, a non-parallel layer moisture determiner **148** determines the moisture content of bale **12** when the ratio is substantially not equal to the predetermined constant *K*.

Non-parallel layer moisture determiner **148** preferably determines the moisture content of bale **12** by using an empirical function

$$W = W_y + 3.2 \times 10^{-2} \frac{(\gamma - 1)}{K}$$

where W is the moisture content of the signal, W_y is the moisture content of one of the mutually orthogonal components which passed through bale **12** in a direction normal to layers, γ is the ratio, and K is the predetermined constant.

Figure 8 illustrates the behavior of the antenna signal of the embodiment of Figures 7A and 7B. Antenna signal **38** starts at a generally low background level **150** which climbs to an initial higher level **152** at a time T_0 when bale **12** (not shown) enters the region between microwave radiation source **28** (not shown) and receiving antenna **36** (not shown). Antenna signal **38** then reaches a first extraneous peak **154** during time interval T_1, due to edge transition effects caused by the leading edge of bale **12** passing between microwave radiation source **28** (not shown) and receiving antenna **36** (not shown). During this time, a first portion of source beam **32** passes through bale **12** (not shown), and a second portion does not, causing these edge

transition effects.

Once bale 12 (not shown) is correctly aligned between microwave radiation source 28 (not shown) and receiving antenna 36 (not shown), for example as in Figures 7A and 7B, antenna signal 38 goes to a steady level 156 during time interval T_2 and remains substantially constant during this time interval, except for fluctuations due to local inequalities in the moisture content and structure of bale 12. During time interval T_2, the alignment signal is produced, and all moisture measurements of bale 12 are made. At time T_3, the trailing edge of bale 12 (not shown) starts to move past microwave radiation source 28 (not shown) and receiving antenna 36 (not shown), causing a second extraneous peak 158, again due to edge transition effects caused by the trailing edge of bale 12.

Figure 9 is a block diagram of an exemplary method for determining the moisture content of tobacco according to the present invention. The method of the present invention can be used with any of the embodiments of the device as described herein, as well as with any of the described methods for performing the calculations of the moisture content of the tobacco material.

In step one, a first portion of the module of tobacco moves between a source of microwave radiation and a receiving antenna. In step two, once the bale is correctly aligned between the source of microwave radiation and the receiving antenna, the alignment signal is produced. In step three, at least one, and preferably a plurality, of moisture measurements are made substantially as described for Figures 2-7, 9 or 10. More preferably, in step three the effect of the tobacco material itself is removed from the measured moisture content in order to more accurately determine the moisture content of the material. Most preferably, such an effect is determined empirically, as described in greater detail below.

In step four, the manufacturing process of the tobacco product, such as cigarettes, pouch tobacco or chewing tobacco, is preferably adjusted according to the moisture content of the material. For example, if the moisture content of the tobacco material is above a pre-determined level, preferably the stored tobacco is processed more quickly, such that the period of storage is reduced. Alternatively and preferably, the manufacturing process is adjusted according to the moisture content of the tobacco material such that the finished tobacco product has a moisture content within a pre-determined, acceptable range, which is approximately 12-18% for loose leaves, and 11-13% for processed tobacco.

Figure 10 shows a flow chart of the calculations for determining the moisture content and density as relating to internal structure of the tobacco module, particularly for bales of tobacco.

The attenuation is used to determine the raw moisture content of the material, while the phase shift is used to determine density of the material. Both the attenuation and the phase shift are preferably used in combination with empirically determined correction factors to calculate final values of moisture content and density of the material.

The first step in the flow chart is the scanning of the material, which can be performed using the device essentially as described in any of the embodiments above. The material is scanned by transmitting a plurality of microwaves through the bale so that they pass through the bale and are received on the other side. From this scanning step, the phase shift and the attenuation are calculated, as shown in step 2. The flow chart now branches into two parts. The right branch shows the steps used in calculating the raw moisture content of the material, while the left branch shows the steps for the determination of density of the material. For clarity, steps in the right (moisture content) branch will have the letter "a" appended; e.g., "3a", "4a", etc. Steps in the left (internal structure) branch will have the letter "b" appended; e.g., "3b", "4b", etc.

Following the right branch, in step 3a an algorithm is used to filter the data points obtained for the attenuation. Each time a measurement of the attenuation is made as described above in Figure 2, a data point is obtained. These data points must be filtered, since otherwise artefactual data could be obtained.

Once the data has been filtered, the attenuation is corrected for the effect of the weight of the material and the bale, as shown in step 4a. This correction is preferably performed by compensating the attenuation with the ratio of a standard weight to the actual weight, for example by multiplication when the material is tobacco, and produces a weight-corrected attenuation value. Next, in step 5a, the weight-corrected attenuation value is preferably corrected for temperature, to produce a temperature-corrected attenuation value. The correction is performed by adding the weight-corrected attenuation value to the factor $\alpha(1 - Ts/Te)$, where Ts is the standard temperature, and Te is the measured temperature of the material, in order to produce the temperature-corrected attenuation value. The temperature of the material is preferably measured by inserting a temperature probe into the bale, for example. The value of α is empirically determined according to the type of material. More preferably, the temperature is substantially continuously monitored by the temperature sensor, so that each measurement of the attenuation can be corrected with the temperature value taken as the transmission of microwaves was made. The temperature-corrected attenuation value thus is compensated for the effect of measurements at different temperatures.

In step 6a, the complete set of all temperature-corrected attenuation values from a single

slice of material is used to calculate a raw moisture value for that slice. This calculation is performed according to a function which can be a linear integration of all the temperature-corrected attenuation values or else a polynomial, depending upon such empirical factors as the type of tobacco material being measured, the shape and structure of the bale itself. In any case, these empirical factors are included in the calculation, so that their effects on the measurement can be compensated for. For example, these factors include but are not limited to the type of tobacco leaf, and the form of the tobacco such as loose leaves or a type of bale.

This raw moisture value will be used in the determination of the final moisture value for the slice of material. However, the final moisture value cannot be determined without knowing the density of material, which is calculated as shown in the left branch of the flow chart.

Turning back now to the left branch, which includes steps for calculating the density of the tobacco material, the density is calculated from the phase shift, in accordance with empirical information from a database. The empirical information includes the type of tobacco material and the structure of the bale itself.

Additionally, the database preferably contains "fuzzy descriptors" which are used to find the correct phase region and to determine the proper relationship between measured phase shift values and calculated density values. These "fuzzy descriptors" are obtained by collecting phase shift data from an analysis of test modules of tobacco having known features, and then comparing the calculated density values with the true, known density values of the test module. From this analysis of the test module, the proper correlation between the measured phase shift values and the calculated density values can be determined. Since this correlation depends both upon the structure of the test module, and upon the type of tobacco material or materials from which the test module is constructed, such an analysis must be performed for substantially every structure of module and type of tobacco material in order to obtain these empirically based correlations.

In step 4b, any deviation of the measured density of the slice of material from the previous measurement of the density of the previous slice is determined. Such deviations are important because they reveal potential foreign components and/or non-uniformities in the internal structure of the tobacco material.

In step 5b, the true density of material is calculated in one of two different ways, depending upon deviations in the calculated density when comparisons are made between two or more slices. In the first method, the deviation in the calculated densities between a plurality of slices is relatively small, such that a single density value can be used for all subsequent

calculations. Alternatively, the deviation between the calculated densities of a plurality of slices is relatively large, such that a plurality of density values, and preferably all density values, are used for the subsequent calculations.

Finally, in step 7, the true density value or values, and the raw moisture value, which is calculated in step 6a, are combined to determine the true moisture value. The equation for calculating the true moisture value includes both the true density and any deviations in the calculated density within the slice, as well as an empirically determined correlation factor. The correlation factor depends upon the type of tobacco material and the structural features of the module of material, which are empirically determined from calibration samples of tobacco . In addition, preferably substantially continuous feedback of previously acquired moisture measurements is also correlated with the current moisture measurement as a correction function. The true moisture value is then output, for example by displaying on a display unit which could include a video screen, or by other devices for displaying the information. Preferably, any deviations in density relating to internal structure of the material which were found by comparison of the measured phase shifts are also displayed, since such information is very useful to a manufacturer of tobacco products.

Figures 11A-11D show various types of moisture measurements for tobacco which were performed according to the present invention. Figure 11A is a graph of the true moisture content as a weight percentage (x-axis) against the ratio of the measured attenuation to the measured phase, which represents density (y-axis). Six types of tobacco were measured (burley and flue cured, with lower, middle and upper stalk for each) in various structures. The density varied from 155 kg to 300 kg per cubic meter. As shown, a very good correlation was obtained between the true moisture content and the measured attenuation and phase ratio. The standard deviation was only 0.4% of the true moisture content. Thus, the method of the present invention was clearly able to accurately measure the moisture content of the tobacco.

Figure 11B shows the results of the phase shift measurements alone (y-axis) against the true moisture content of the material for the measurements described for Figure 11A. As can be seen, without any correction for the density deviation or correlation with the attenuation, the values of phase shift are not as correlated with the true moisture content. The spread of the phase shift values compared to the true moisture content is caused by the significant deviations of the density of the material, which included packages of tobacco. Similarly, for Figure 11C, the measured attenuation values (in dB) alone were also spread when correlated with the true moisture content, again caused by the density deviation of the packages of tobacco. The

standard deviation was 1.1% of the true moisture content, higher than the 0.4% deviation obtained when the measured phase shift and attenuation values were correlated as shown in Figure 11A. Clearly determination of moisture content of tobacco material using both measured phase shift and attenuation data, according to the method of the present invention, results in measured moisture content being much more closely correlated to the true moisture content of the material.

Figure 11D shows the measured amplitude or phase of the tobacco material, performed according to the method of the present invention (y-axis) for each data point obtained (x-axis). The measurements were performed with two frequencies of microwaves, F_1 and F_2, in which $F_1 > F_2$. The device and method of operation are described with regard to Figure 12 below. Briefly, both the attenuation and phase shift are determined at the two frequencies of microwave radiation, as shown. A table of the measured values is given below.

Table of measured values

Data point	Attenuation	Phase shift
Data Region F_1 = 3.24 GHz		
1	13.62	34.77
2	13.62	34.83
3	13.62	34.73
4	13.62	34.64
5	13.62	34.77
6	13.62	34.86
7	13.62	34.7
8	13.62	34.77
9	13.62	34.86
10	13.62	34.73
Data Region F_2 = 3.45 GHz		
11	13.88	115.69
12	13.87	115.53
13	13.88	115.63
14	13.88	115.63
15	13.87	115.53
16	13.88	115.53
17	13.87	115.59

These values are then used to calculate the moisture content of the material, by first correcting the phase shift according to the following equation:

$$Ph_{F_1} = \frac{\Delta Ph(F_2) - \Delta Ph(F_1)}{F_2 - F_1} F_1$$

For this equation, F_1 is the first frequency and F_2 is the second frequency; Ph_{F_1} is the measured phase shift for the first frequency F_1; and $\Delta Ph(F_1)$ and $\Delta Ph(F_2)$ are the phase shifts for F_1 and F_2, respectively. Taking exemplary values from the above Table, the equation was solved as follows:

$$Ph_{F_1} = \frac{115.6 - 34.7}{3.45 - 3.24} 3.24 = 1248$$

Next, the true phase shift was determined as follows.

$Ph_{F1} / 360 = X_1$

$(\mathrm{mod}(X_1) * 360) + \Delta Ph(F_1) = P_{true}$

Briefly, first, the measured phase shift Ph_{F1} (1248 degrees) was divided by 360 to obtain 3.47 (X_1). The modulo of 3.47 was taken to obtain 3, and which was then multiplied by 360 to get 1080, after which $\Delta Ph(F_1)$ was added to obtain the true phase shift (P_{true}), or 1114 degrees. *A(dB)/Ph(degrees)* = 13.62 dB / 1114 degrees = 0.012. From the previous graph of the ratio of the attenuation to the phase shift (Figure 11A), the ratio value of 0.012 yielded a moisture content of 11.2 percent.

Figure 12 shows a schematic diagram of another preferred embodiment of the present invention, in which the system described previously has been adjusted to permit transmission of more than one frequency of microwave radiation. It should be noted that this preferred embodiment can be used to determine the moisture content of tobacco material having substantially any structure as encompassed by the term "module", including bales, bales and/or any other bulk of tobacco material. Thus, a module can have a substantially irregular structure with variable density.

A multiple-frequency system **160** has a multiple-frequency transmitter **170** for sequentially transmitting microwave radiation at a plurality of frequencies. The frequency to be transmitted is selected by a frequency controller **172**. Transmitter **170** then causes a transmitting antenna **172** to transmit microwave radiation at the desired frequency. The transmitted microwave radiation then passes and/or is reflected through a module or bale of material (not shown) and is received by a receiving antenna **174**. Receiving antenna **174** sends a signal to a signal receiver **176**. Signal receiver **176** is preferably a heterodyne receiver. Substantially simultaneously, a reference signal is sent from transmitter **170** to a reference receiver **178**, which is also preferably a heterodyne receiver. Signal receiver **176** sends a measurement signal (labeled as "I.F. 1") to a detector **180**, while reference receiver **178** sends a reference signal (labeled as "I.F. 2") to detector **180**. Detector **180** uses the reference signal to determine the correct attenuation of the measurement signal, and then passes both signals to a phase detector **182**, which determines the correct phase shift for the measurement signal.

The gross phase shift difference between two phase shifts measured after microwave radiation of two different frequencies has been transmitted through the material can be described as follows.

Δ P(gross) = $F_2/(F_2-F_1) * (P_2 - P_1)$

The final phase shift difference is:

Δ P (final) = Pi + Pg mod (2π)

Thus, the gross phase shift difference is obtained by sequentially transmitting microwave radiation of at least two different frequencies, and "hopping" or alternating at least between these two frequencies at each point in the material.

The equations which describe the phase shift and attenuation are as follows.

1. λ=C/F; l= (wave length of radiation); ε'= (dielectric constant of material)

2. $P_1 = \frac{2\pi}{\lambda_1}\sqrt{\varepsilon'}\, l$;

3. $P_2 = \frac{2\pi}{\lambda_2}\sqrt{\varepsilon'}\, l$;

4. $P_1 = KF_1$; $P_2 = KF_2$; $K = \frac{2\pi}{C}\sqrt{\varepsilon'}\, l$; $P_1 - P_2 = \Delta P = K(F_1 - F_2)$;

5. $P_1 = Ph_{(t)}(F_1)$; $P_2 = Ph_{(t)}(F_2)$;

6. $K = \frac{P_1 - P_2}{F_1 - F_2}$; $(F_1 > F_2)$

7. Pg= (phase including $n\pi$ term) = $K \bullet F_i$ (i is 1 or 2)

8. Corrected Phase-shift = $(Pg - n\pi) + \frac{P_1 - P_2}{2}$; $n = (Pg - n\pi > 0)$

Note that F is the frequency of the microwave radiation; l is the length of the beam path as it passes through the material of the module; ε' is the dielectric constant of the bulk of material; P_1 is the phase deviation for microwave radiation at frequency F_1; P_2 is the phase deviation for microwave radiation at frequency F_2; $K(F_1 - F_2)$ is the difference between the phase deviation of the radiation at frequencies F_1 and F_2; $P_{h(t)}$ is the true phase shift, such that the measured phase shift, P_1, is a function of the true phase shift and of the frequency F_1, for example; Pg is the gross phase shift difference; and n is the largest number which satisfies

equation 8 such that $Pg - n\pi$ is greater than 0.

Although these equations both describe the corrected phase shift and can be used for its calculation, the refinements of the calculations must be done according to empirically observed properties of the material itself and effects of the surrounding environment. In step 1, a plurality of frequencies of microwave radiation are sequentially transmitted through the material in a module. In step 2, the attenuation and the corrected phase shift are calculated for the plurality of frequencies of microwave radiation.

In step 3, an algorithm is performed to filter noise from the calculated values of the attenuation and the corrected phase shift. The attenuation for a frequency F_{2i} can be described as $A_{2i} = a_1 A_{1i} + b_1$. Similarly, the phase shift is $P_{i2}=a_2 P_{1i} + b_2$. Note that A_{1i} and P_{1i} are the attenuation and phase shift values obtained from the previously measured frequency F_{1i}. The values for a_1, a_2, b_1 and b_2 are taken from a database, depending upon the particular application and type of material. For example, one set of values would be required for tobacco in a bale, while another set of values would be required for a loose pile of tobacco leaves. These values are empirically determined based upon empirical measurements of the material concerned. This calculation to filter noise is preferably performed upon all calculated values of the attenuation and the corrected phase shift. In addition, the value of each of the plurality of frequencies is used for these calculations, since the attenuation and phase shift values are also dependent upon the frequency of the microwave radiation.

Preferably, any 'edge' measurements, or measurements of microwave radiation transmitted through or reflected by an edge of material are eliminated from any subsequent calculations since these measurements are considered extraneous. The determination of whether a particular measurement is an 'edge' measurement can be made in a number of ways. For example, the location of the module relative to the beam can be determined, such that when an edge of the module is about to be impinged by the microwave beam, a signal can be sent to the attenuation and phase shift determiners. Alternatively and preferably, the measurement of the attenuation can be plotted, and any extraneously high peaks or low troughs of attenuation can be eliminated, for example by removing any values which are more than two or three standard deviations from the average attenuation. Thus, any extraneous 'edge' measurements are preferably eliminated at this stage of the analysis.

In step 4, density and moisture content of tobacco material are calculated from the plurality of filtered attenuation and filtered phase shift values, preferably from all of these values. The moisture content of the material is determined from the following equation:

$$W_{m} = \sum_{i=1}^{n} W_i * r_i$$

in which r_i is the correlation factor described previously. The term W_i is a function of the attenuation A_2 and the phase shift P_2 as determined in step 3, as well as of the type and structure of material. The correlation factor is obtained from a database of these values, determined from empirical observation.

Values of material density are then calculated from a statistical function of the sum of the phase shift values, again taken from the database. This function depends upon the characteristics of the material being analyzed, as for the calculation to filter noise described for step 3. Also, the density is a function of both P_2 as determined in step 3, and the type and structure of the material. Thus, the necessary information is taken from a database of empirically determined information.

Preferably, at this stage any defects in the material are detected by examining the densities collected for a portion of the material. The defect could include an irregular moisture distribution within the interior of the material, such as an unusually high moisture content within the material, and the presence of a foreign component and/or non-uniformity inside the tobacco material, for example.

In step 5, temperature of the material is preferably compensated for during determination of moisture content and density, if necessary. Again, the necessity for step 5 is determined at least partially according to empirical observations.

In step 6, moisture content and density of the material are output, for example to a display on a computer screen or by printing onto paper.

The advantages of determining moisture content and density of each point in a material at more than one frequency of microwave radiation are as follows. First, measuring the attenuation and phase shift at one point in the material but with more than one frequency permits averaging of the values to obtain a more accurate result. Second, the change in the attenuation is linear, so that alterations in the attenuation due to the measurement at different frequencies can be easily calculated. Any remaining differences are then removed by averaging. Third, a good range of frequencies for any particular type or form of material can be selected, rather than relying upon a single frequency. Finally, measurements at the chosen range of frequencies also enable the true phase shift to be determined.

The third point, the ability to choose a good range of frequencies for a particular type or form of material, is particularly important for mixed materials, or materials containing more than

one type of substance. For example, tobacco leaves are often mixed with unneeded raw material components such as stems, which affect the measured moisture content of the tobacco leaves themselves. Additionally, this mixture of different types of materials with different properties causes harmonics to appear in the transmitted microwaves. However, the true phase shift can be determined from a linear portion of the curve of phase shift plotted against frequency. Thus, using a plurality of frequencies can simplify the determination of the phase shift for mixed materials.

Optionally and preferably, a frequency range of microwave radiation can be chosen which minimizes reflection of radiation by the material and maximizes transmission of microwave radiation through the material. More preferably, a range of suitable frequencies is chosen from a database before microwave measurements are made. The choice of a particular range is empirically based on such factors as the type of material and the structure of material. Therefore, tobacco in a bale would require a different range of frequencies than loose tobacco leaves, for example. During real-time acquisition of microwave measurements, the frequency range can also be selected to reduce or eliminate normal levels of background noise caused by environmental effects and possible interference. An example of such interference could be a cellular phone. Preferably, more than one frequency range is examined before selecting a particular range in which to make the measurements, in order to reduce or eliminate this problem.

In addition, preferably adjustments are made to the selected range of frequencies, such that more measurements are made within a smaller range of frequencies which gives the best results. Thus, adjustments to the frequency range made 'on the fly' enable the most sensitive and accurate measurements to be made.

According to still another preferred embodiment of the present invention, there is provided a method for determining the internal structure of a package of material, such as tobacco for example, from at least one of the moisture and density measurements from the received microwaves, or a combination thereof. For the purposes of description only, the following example focuses on the analysis of the structure of a package of tobacco, it being understood that this is only an illustrative example and is not intended to be limiting in any way.

Preferably, each portion of the package of tobacco is analyzed by passing between the transmitting and receiving antennas, as previously described. More preferably, such measurements are performed using microwaves at a plurality of frequencies, in order to obtain a set of measured results for each portion of the package of tobacco. The output of the microwave

data acquisition is, for each portion of the package through which microwaves are transmitted, a set of at least one of measured moisture and density values, and more preferably a combination of both values, each measured value obtained from microwaves at a different frequency. Each measured value is then processed in order to obtain an indication of the differential between the moisture content and/or density of that portion and the moisture content and/or density of surrounding portions.

Typically, each moisture and/or density differential corresponds to at least a portion of a foreign object and/or foreign matter (collectively referred to as a 'foreign component'), or a lack of uniformity of the material itself, such as a non-uniformity of the moisture content and/or density of the material, all of which are collectively referred to herein as a 'target'. For example, a lack of uniformity of the material itself could be caused by excessively high moisture content, an air pocket, or more loosely packaged material, in a localized portion of the package of material.

Each target is classified as belonging to one of a standard set of moisture content and density types. For each target, the location and relative size of the target is obtained by scanning along at least one axis, and more preferably by scanning along at least two axes, and most preferably by scanning along three axes of the portion of packaged material. Obtaining values from measurements along a plurality of axes is preferred for greater accuracy and precision, and in order to reduce the number of falsely identified moisture content and/or density variations in the material. These values are mapped separately for each target class as described in greater detail below. The array of mapped values constitutes a collective descriptor vector for all the targets. A relationship is provided that relates the descriptor vector to a size vector of the target, where size refers to, for example, an area occupied by the foreign object or volume, and/or area of the non-uniformity per unit volume and/or area of the package of tobacco, depending upon the number of axes along which measurements are taken. This relationship is used to infer the relative area and/or volume of the foreign components and/or non-uniformities from the descriptor vector.

The set of standard density types, and the relationship between descriptor and size vectors of the targets are obtained by a calibration procedure. A set of standard calibration samples of known compositions, moisture contents, and densities is provided. These calibration samples may be different collections of tobacco leaves mixed with foreign components and/or having non-uniformities of various sizes, as well as of various moisture contents and densities. For each calibration sample, one or more sets of pairs of moisture content and/or density values

at different frequencies of microwaves are acquired. These pairs of values are compared to standard values for tobacco leaves alone. Locations within the collections of mixed tobacco leaves and foreign components with measured moisture content and/or density differential values which exceed the threshold are grouped into calibration targets. For each calibration target, values of size parameters such as area or volume are calculated. Values of the size parameters and of the moisture content and/or density parameters are classified by cluster analysis to obtain the standard target types.

The calibration samples are analyzed by a prior art method, if necessary, to obtain a set of patterns for detecting various features. These features are computed with the moisture content and/or density parameters by standard computational methods, for example by training a neural net.

The output of the training of a neural net is a trained neural net whose inputs are descriptor (moisture content and/or density) vectors and size (area and/or volume) vectors, and whose outputs are patterns of features which may be considered desirable or undesirable to have in the packaged material. The neural network is trained by using the calibration descriptor vectors and calibration size vectors as a training set. The desired relationship between descriptor vectors and size vectors, and hence the pattern of 'good' or 'bad' features then is the trained neural network. See, for example, P. Yu. V. Anastassopoulos and A. N. Venetsanopoulos, "Pattern classification and recognition based on morphology and neural networks", *Can. J. Elect. and Comp. Eng.*, Vol. 17 No. 2 (1992) pp. 58-59 and the references therein.

A preferred embodiment of the calibration and target detection procedure is now described with regard to the flowchart shown in Figures 13A-13B. The calibration and target detection procedure includes two loops, one over N calibration samples and one loop for detecting targets in actual packages of material. In the first loop, at least one measured value of moisture content and density, and preferably both, of the calibration samples are acquired, and the database target types are determined. In the second loop, actual packages of material are examined and targets are identified within these packages.

Referring to Figure 13A, in the first loop, moisture content and/or density values are acquired as previously described, according to any of the embodiments given above, as shown in step 1. Preferably, these values are obtained from determination of multiple vectors as described above, resulting from transmission of microwaves along at least one axis of the packaged material.

After a pre-determined number of relevant moisture content and/or density values of a

pre-determined number of samples has been collected, targets are detected in step 2. Values of moisture content and/or density parameters of each target are computed, and the database target types are obtained by applying cluster analysis to the resulting set of moisture content and/or density parameter values, as shown in step 3. These database target types are used to define target classes, thereby enabling classification of targets in calibration samples, according to these classes in step 4. Calibration samples are also analyzed according to standard techniques in order to determine actual moisture content and/or density values in step 5. Alternatively, known values of moisture content and/or density could be assigned to calibration samples of known compositions, prepared by varying amounts of tobacco leaves and different foreign objects and/or foreign matter. Known moisture content and/or density values are then compared to measured moisture content and/or density values in step 6. The trained neural net or other pattern detection algorithm is then applied for detecting patterns in step 7, and for assigning these patterns to categories such as "problematic", "good" and so forth.

Referring to Figure 13B, in step 1 of the second loop, for detecting targets in actual packages of material, again moisture and/or density values are acquired for the package. In step 2, the initial target detection is performed with empirically determined values obtained from a database as shown, in order to determine possible features of interest in each target.

In step 3, the potential targets are classified according to a clustering algorithm, by using the measurement vectors for the moisture content and/or density values in a linear statistical analysis. Preferably, multiple vectors and/or multiple microwave frequencies are used for mapping these targets, in order to reduce the possibility for false target identification. The multiple vectors are obtained if microwaves are transmitted through the material along a plurality of axes, such that the moisture content and/or density values are calculated for a plurality of vectors.

In step 4, fuzzy logic and/or classical statistical analysis are used for final determination of targets in an actual sample of packaged material .

Figure 14 shows the target classification process (step 3) included in Figures 13A-13B in more detail. In step 1 of the target classification process, for each target, features of interest are determined. For example, various features appearing in graphical plots of the measurements, such as maximum peak, minimum peak, standard deviation between peaks, apparent size of the target (dimensions for which are determined according to the number of vectors for which measurements are obtained), width of a peak, and overall number of peaks, are selectively detected for each potential target.

In step 2, the target type is determined by examining all of the features in order to place the target within a particular class. In step 3, pattern recognition is performed by using methods of pattern classification and recognition. In practice, for example, during a manufacturing process involving packaged material, a pattern may be classified in relation to a quality control problem associated with the packaged material, such as an air pocket (area of non-uniformity within the packaged material), absence or surplus of one or more objects in a package required to have a specified number of discrete objects, or an area of unacceptably high moisture content. In step 4, one or more targets in an actual sample are recognized and identified according to the classified patterns.

It should be noted that although this procedure is described with regard to moisture content and density values, which are obtained from attenuation and phase shift measurements, a similar procedure could be performed using frequency shift and/or changes in microwave resonator quality, as described in U.S. Patent Application No. 09/143,966, incorporated by reference as if fully set forth herein.

Figures 15 – 18 are examples of actual scenarios of application of the device and method of the present invention. In each scenario, there is a commonly occurring problem related to moisture content and/or density of some form of tobacco material. Pattern detection, classification, and recognition are applied to the microwave measurements performed on each tobacco material, in order to identify and characterize the problem. This information is very useful as quality control feedback for improving a manufacturing process involving tobacco material.

In Figure 15, moisture content and density values are determined for multiple portions of a tobacco bale, preferably several hundred of such portions. When the ratio of moisture content to density (y-axis) is plotted as a function of a linear dimension of the bale (x-axis), a 'blip' (shown in circle) in the curve clearly indicates the presence of a non-uniformity of the material.

Figures 16A-16C show other classifiable patterns of internal structure recognizable in tobacco bales. Again, moisture content and/or density, or a ratio thereof, is plotted against a linear dimension of the bale. Peak characteristics such as size, shape, number and so forth, are determined as previously described. Figure 16A shows a classifiable pattern of an area having excessively high moisture, Figure 16B shows a classifiable pattern for a poorly pressed area of material and Figure 16C shows a classifiable pattern for an air pocket.

Figure 17 illustrates detection of one or more objects or units missing from a box or

carton required to have a specified number of discrete objects or units. As a practical example, a cigarette manufacturing process involves packaging a pre-determined specified number of cigarette packages into each of several larger cartons. Part of quality control of such a manufacturing process could include monitoring the number of cigarette packages placed into each carton along an assembly line. Package Profile (A) shows a plot of a package density parameter as a function of carton sample or carton number along a cigarette carton packaging line. This plot is representative of all samples or cigarette cartons being full according to a given packaging specification. In Packaging Profile (B), focusing on a noticeable decrease in the package density parameter, there is detection of a carton, at an identifiable location in the packaging line, missing one or more cigarette packages.

Figure 18 illustrates applicability of pattern recognition data processing of microwave measurements involving acquisition of both transmitted (TU) and reflected (RU) microwave signals. Reflection of part of the microwave radiation transmitted into packaged tobacco occurs, for example, when analyzing cigarette end products such as cigarette cartons featuring individual packages of cigarettes, where each package of cigarettes includes an aluminum foil wrapper. Due to the nature of interaction between the microwave radiation and the aluminum wrapper, at least part of the initially transmitted microwave radiation is reflected out of the cigarette package and received by the receiving antennae, while the remaining part of the initially transmitted microwave radiation passes through the cigarette package and is also received by the receiving antennae. The signals obtained from the received, reflected microwave radiation as the material is scanned by transmitting the microwave radiation, are used to build a reflection vector. The reflection vector is optionally used for pattern recognition and target detection, substantially as previously described for density measurements. The device and method of the present invention are applicable to other instances where a metal or other microwave radiation reflecting material is present in a sample of packaged tobacco.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made.

WHAT IS CLAIMED IS:

1. A method of determining a moisture content of tobacco material, the method comprising the steps of:

(a) transmitting a plurality of microwaves substantially through at least a portion of the material, such that said microwaves are transmitted microwaves;

(b) receiving said transmitted microwaves such that said microwaves are received microwaves;

(c) determining an attenuation from said received microwaves;

(d) using at least one empirical factor selected from the group consisting of weight of the material, temperature of the material, structure of the material and type of the tobacco material to correct said attenuation, producing a corrected attenuation; and

(e) calculating the moisture content of the tobacco material from said corrected attenuation.

2. The method of claim 1, wherein the step of determining said attenuation further comprises the step of determining a phase shift from said received microwaves.

3. The method of claim 2, wherein the step of determining said attenuation further comprises the step of:

(i) repeating steps (a) to (c) for at least a portion of the material on the bale, such that a plurality of phase shifts and a plurality of attenuations are obtained, and such that a plurality of corrected phase shifts are produced according to said plurality of phase shifts.

4. The method of claim 3, further comprising the step of:

(ii) determining a density of the material from said phase shifts; and

(iii) calculating a final moisture content of the material from said density and from said raw moisture content.

5. The method of claim 3, wherein the material features an internal structure and an irregularity of said density of said internal structure is calculated by comparing one of said

plurality of phase shifts to a previous value of said phase shifts, such that said irregularity is detected if one of said plurality of phase shifts differs from said previous value.

6. The method of claim 5, wherein said irregularity of said density of said internal structure indicates that the material is of more than one type of tobacco.

7. The method of claim 3, wherein a first phase shift is determined for microwave radiation of a first frequency F_1, and a second phase shift is determined for microwave radiation of a second frequency F_2, said first phase shift being corrected to form a first measured phase shift according to the equation:

$$Ph_{F_1} = \frac{\Delta Ph(F_2) - \Delta Ph(F_1)}{F_2 - F_1} F_1$$

wherein Ph_{F_1} is said measured phase shift for said first frequency F_1; and $\Delta Ph(F_1)$ and $\Delta Ph(F_2)$ are said phase shifts for F_1 and F_2; and wherein a first corrected phase shift is formed according to the following steps:

(i) $Ph_{F_1} / 360 = X_1$; and

(ii) $(\mathrm{mod}(X_1) * 360) + \Delta Ph(F_1) = P_{true}$;

such that P_{true} is said first corrected phase shift.

8. The method of claim 7, wherein the moisture content is determined according to a ratio of said attenuation and said corrected phase shift.

9. The method of claim 8, wherein an empirical curve of a relation between said ratio and the moisture content is provided, such that the moisture content is determined according to said ratio by using said empirical curve.

10. The method of claim 1, wherein the tobacco material is contained in a module.

11. The method of claim 10, wherein said at least one empirical factor is a plurality of empirical factors selected from the group consisting of weight of the module, type of the material, structure of the module, location of the module relative to said plurality of microwaves and temperature, and said factors are stored in a database.

12. The method of claim 11, wherein said corrected attenuations and said phase shifts are further corrected by removing attenuations and phase shifts produced after said plurality of microwaves passes through an edge of the module, such that a first portion of said plurality of microwaves passes through said portion of the module and a second portion of said plurality of microwaves substantially does not pass through said portion of the module.

13. The method of claim 1, wherein the step of determining said density includes detecting a defect in the material, said defect being selected from the group consisting of irregular moisture distribution within an interior of the material and presence of a foreign body inside the material.

14. A method for determining a moisture content of tobacco material, the method comprising the steps of:

(a) transmitting a plurality of microwaves substantially through at least a portion of the material, such that said microwaves are transmitted microwaves;

(b) receiving said transmitted microwaves such that said microwaves are received microwaves;

(c) determining an attenuation from said received microwaves;

(d) determining a phase shift from said received microwaves; and

(e) calculating the moisture content of the tobacco material from a ratio of said attenuation and said phase shift.

15. The method of claim 14, wherein the step of calculating the moisture content further comprises the steps of:

(i) providing an empirical curve of a relation between said ratio and the moisture content; and

(ii) determining the moisture content according to said ratio by using said empirical curve.

16. The method of claim 15, wherein the step of determining said attenuation further comprises the step of:

(i) using at least one empirical factor selected from the group consisting of weight of the material, temperature of the material, structure of the material and type of the

tobacco material to correct said attenuation, producing a corrected attenuation;

17. The method of claim 16, wherein the step of determining said phase shift further comprises the steps of:

(i) determining a first phase shift for microwave radiation of a first frequency F_1;

(ii) determining a second phase shift for microwave radiation of a second frequency F_2; and

(iii) correcting said first phase shift to form a first measured phase shift according to the equation:

$$Ph_{F_1} = \frac{\Delta Ph(F_2) - \Delta Ph(F_1)}{F_2 - F_1} F_1$$

wherein Ph_{F_1} is said measured phase shift for said first frequency F_1; $\Delta Ph(F_1)$ and $\Delta Ph(F_2)$ are said phase shifts for F_1 and F_2; and wherein a first corrected phase shift is formed according to the following steps:

(i) $Ph_{F_1} / 360 = X_1$; and

(ii) $(\mathrm{mod}(X_1) * 360) + \Delta Ph(F_1) = P_{true}$;

such that P_{true} is said first corrected phase shift.

18. A method for determining a moisture content of tobacco material, the method comprising the steps of:

(a) transmitting a plurality of microwaves of a plurality of frequencies substantially through a portion of the material, said microwaves of each of said plurality of frequencies being transmitted sequentially such that said microwaves are transmitted microwaves of a particular frequency;

(b) receiving said transmitted microwaves of said particular frequency such that said microwaves are received microwaves of said particular frequency and such that said transmitted microwaves from said plurality of frequencies are received;

(c) determining an attenuation from said received microwaves of each of said particular frequencies, such that a plurality of attenuations is determined;

(d) determining a phase shift from said received microwaves of each of said particular frequencies, such that a plurality of phase shifts is determined;

(e) correcting each of said plurality of phase shifts according to said plurality of phase shifts, such that first phase shift is determined for microwave radiation of a

first frequency F_1, and a second phase shift is determined for microwave radiation of a second frequency F_2, said first phase shift being corrected to form a first measured phase shift according to the equation:

$$Ph_{F_1} = \frac{\Delta Ph(F_2) - \Delta Ph(F_1)}{F_2 - F_1} F_1$$

wherein Ph_{F_1} is said first measured phase shift for said first frequency F_1; and $\Delta Ph(F_1)$ and $\Delta Ph(F_2)$ are said phase shifts for F_1 and F_2; and wherein a first corrected phase shift is formed according to the following steps:

(i) $Ph_{F_1} / 360 = X_1$; and

(ii) $(\mathrm{mod}(X_1) * 360) + \Delta Ph(F_1) = P_{true}$;

such that P_{true} is said first corrected phase shift.; and

(f) determining the moisture content according to a ratio of said corrected phase shift and said attenuation.

19. A method of analyzing packaged tobacco to determine an internal structure of the packaged tobacco, the method comprising the steps of:

(a) performing a calibration procedure on a plurality of calibration samples of the packaged tobacco to determine a plurality of target types, said calibration procedure including a step of transmitting microwaves through at least a portion of each of said plurality of calibration samples;

(b) transmitting a plurality of microwaves substantially to at least a portion of the packaged tobacco , such that said microwaves are transmitted microwaves;

(c) receiving said transmitted microwaves such that said microwaves are received microwaves, said received microwaves include reflected microwaves;

(d) determining a plurality of attenuations from said received microwaves;

(e) determining a plurality of phase shifts from said received microwaves;

(f) calculating a plurality of at least one of a moisture value and a density value of the package of the packaged tobacco from at least one of said plurality of said attenuations and said plurality of said phase shifts; and

(g) analyzing said plurality of said moisture and said density values to determine at

least one target in the packaged tobacco, according to said target types determined from said calibration procedure, said at least one target showing at least a portion of the internal structure of the packaged tobacco.

20. The method of claim 19, wherein said target type is selected from the group consisting of a foreign component in the packaged tobacco, a non-uniformity of moisture of the packaged tobacco, and a non-uniformity of density of the packaged tobacco.

21. The method of claim 19, wherein a pair of said density and said moisture values are calculated.

22. The method of claim 21, wherein a plurality of said pairs is calculated for different frequencies of said microwaves.

23. The method of claim 22, wherein step (a) further comprises the steps of:

(i) preparing a plurality of said calibration samples of known density and moisture values, including at least one said calibration sample of known internal structure including at least one said target type;

(ii) transmitting a plurality of microwaves substantially through at least a portion of the material of each said calibration sample, such that said microwaves are transmitted microwaves;

(iii) receiving said transmitted microwaves such that said microwaves are received microwaves, said received microwaves include reflected microwaves;

(iv) determining a plurality of attenuations from said received microwaves;

(v) determining a plurality of phase shifts from said received microwaves;

(vi) calculating a plurality of at least one of a moisture value and a density value of said known internal structure;

(vii) identifying a plurality of features of said plurality of moisture values and density values;

(viii) performing cluster analysis on said plurality of said features to obtain a database of said plurality of said target types; and

(ix) classifying a plurality of patterns from said database of said plurality of

said target types.

24. The method of claim 23, wherein step (ix) is effected by training a neural net.

25. The method of claim 23, wherein step (g) further comprises the steps of:

(i) detecting potential targets in the internal structure of the packaged tobacco by comparing features of said plurality of said calculated density and moisture values to said patterns of said target types of said calibration samples;

(ii) classifying each said potential target according to a clustering algorithm; and

(iii) determining presence of at least one target in the internal structure of the packaged tobacco according to a numerical method selected from the group consisting of fuzzy logic and classical statistical analysis.

26. A method of analyzing packaged tobacco to detect a presence of at least one characteristic selected from the group consisting of a foreign component and a non-uniformity of the material, by transmitting microwaves through at least a portion of the packaged tobacco , the method comprising the steps of:

(a) performing a calibration procedure on a plurality of calibration samples of the packaged tobacco to determine a plurality of target types, said calibration procedure including a step of transmitting microwaves through at least a portion of each of said plurality of calibration samples;

(b) acquiring a plurality of at least one of a moisture value and a density value of the packaged tobacco by analyzing the microwaves transmitted through the packaged tobacco, said microwaves include reflected microwaves ; and

(c) analyzing said plurality of values to detect at least one potential target, according to said target types from said calibration procedure.

27. The method of claim 26, wherein a pair of said density and said moisture values is acquired.

28. The method of claim 27, wherein a plurality of said pairs is acquired at different

frequencies of microwaves.

29. The method of claim 28, wherein step (a) further comprises the steps of:

(i) preparing a plurality of calibration samples of known density and moisture values, including at least one calibration sample with at least one of the foreign component and the non-uniformity;

(ii) acquiring a plurality of moisture values and density values for each calibration sample by analyzing said microwaves transmitted through said at least a portion of each calibration sample;

(iii) identifying a plurality of features of said plurality of moisture values and density values;

(iv) performing cluster analysis to detect a plurality of target types; and

(v) classifying a plurality of patterns from said plurality of target types.

30. The method of claim 29, wherein step (v) is effected by training a neural net.

31. The method of claim 29, wherein step (c) further comprises the steps of:

(i) performing initial target detection according to a plurality of empirically determined values from said calibration samples;

(ii) classifying each initial target according to a clustering algorithm; and

(iii) determining if each initial target is the at least one characteristic selected from the group consisting of the foreign component and the non-uniformity of the packaged tobacco .

FIG. 1A

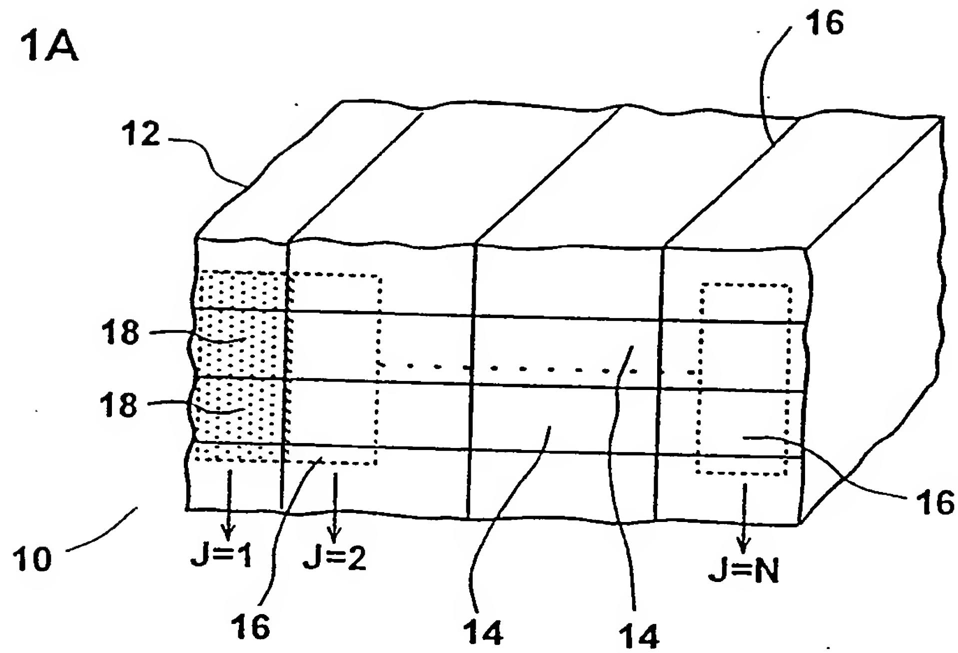
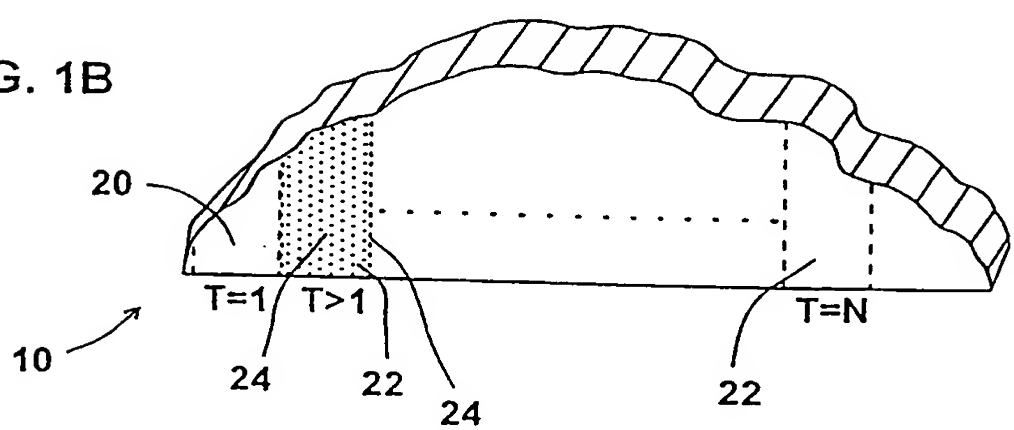


FIG. 1B



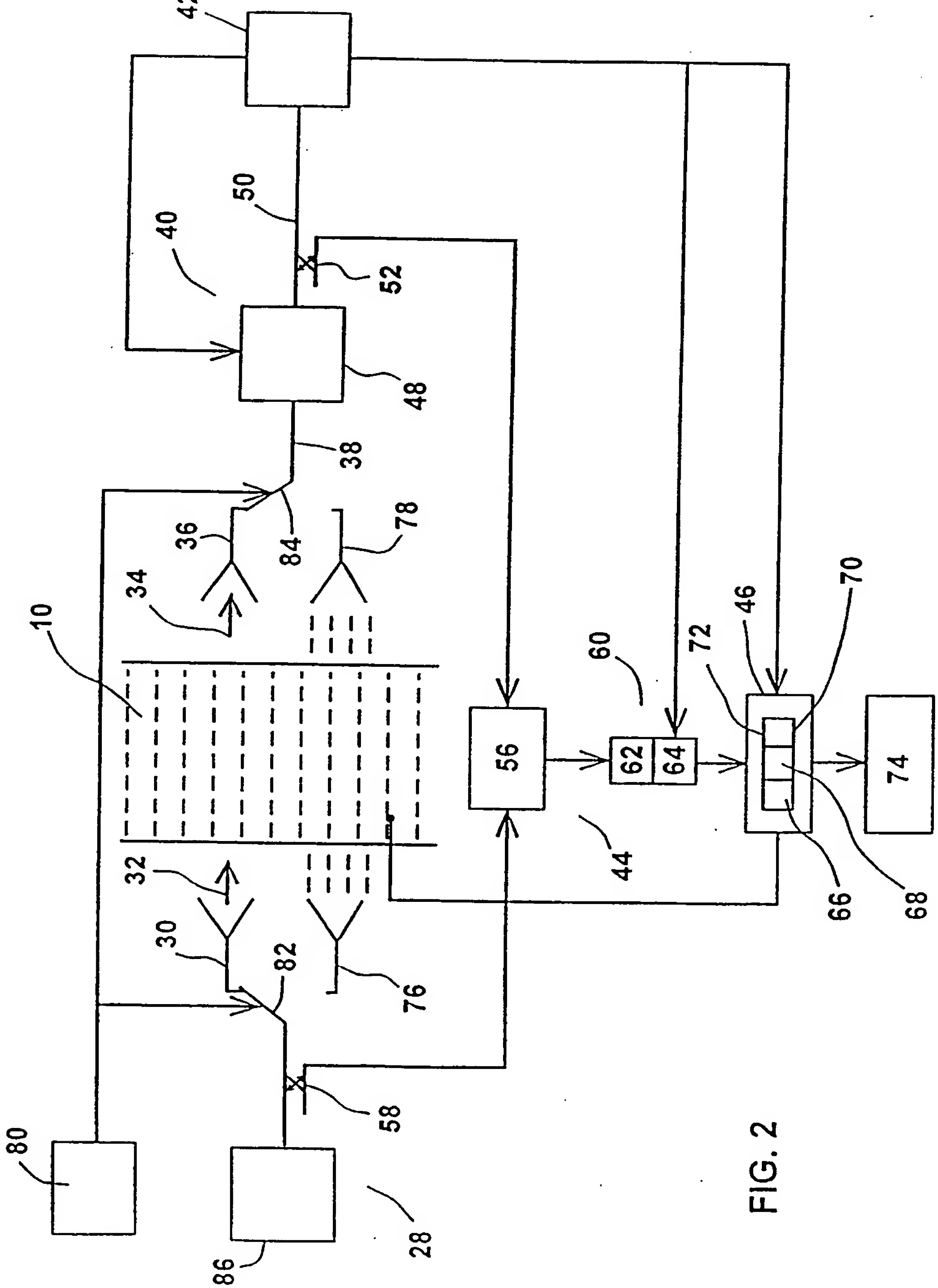

42
50
40
52
48
38
84
36
78
34
10
60
72
46
70
56
62
64
74
44
32
30
82
76
66
68
58
80
86
28

FIG. 2

FIG. 3

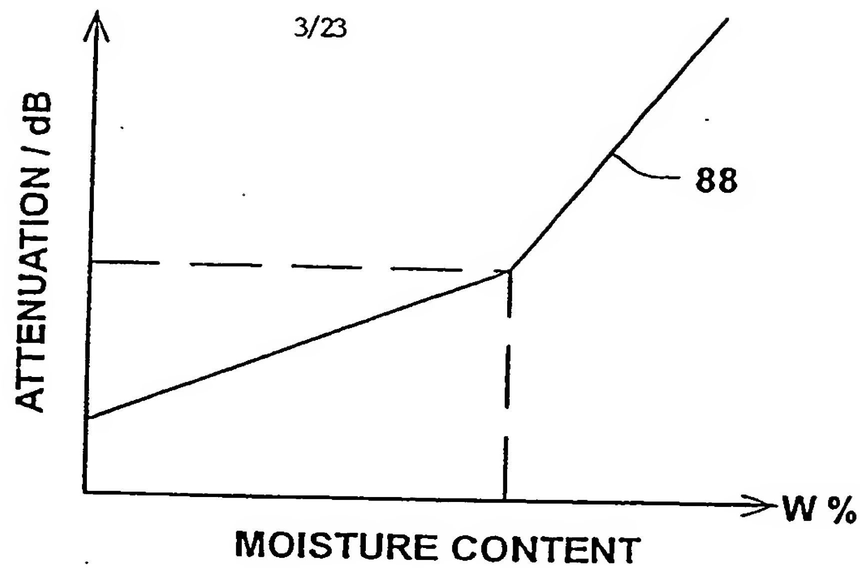
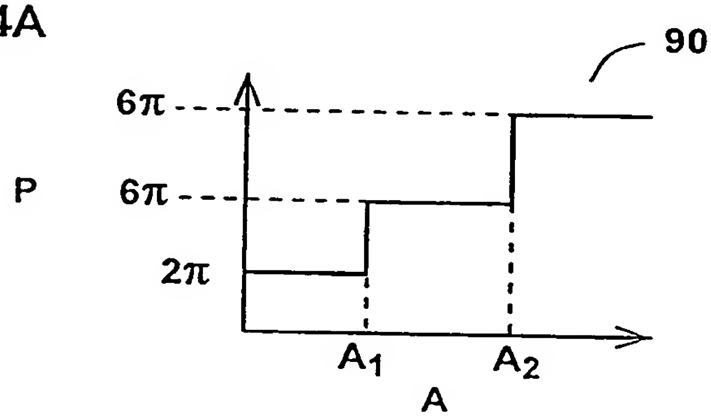


FIG. 4A



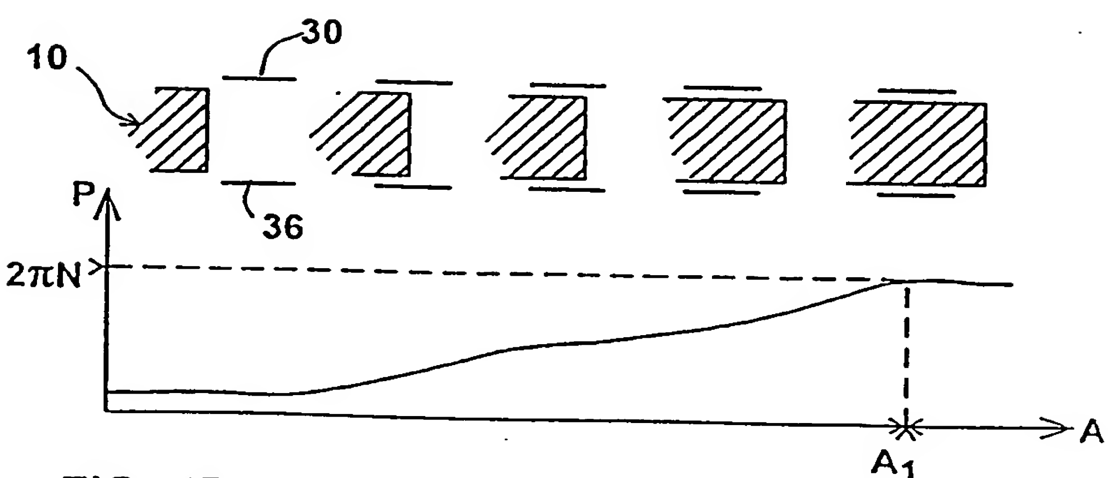


FIG. 4B

FIG. 5A

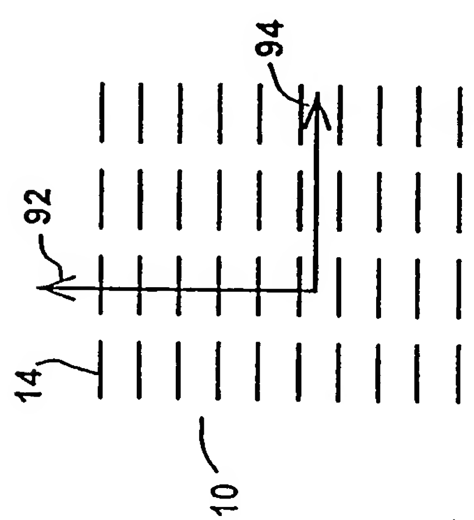


FIG. 5B

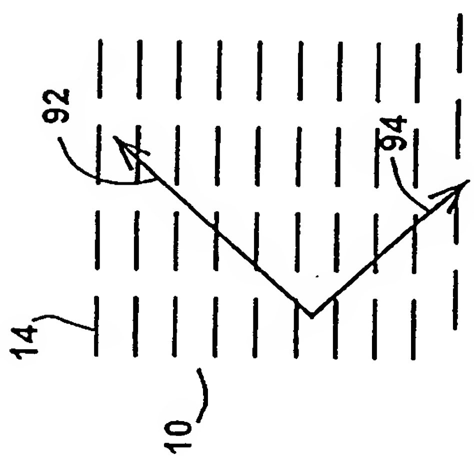
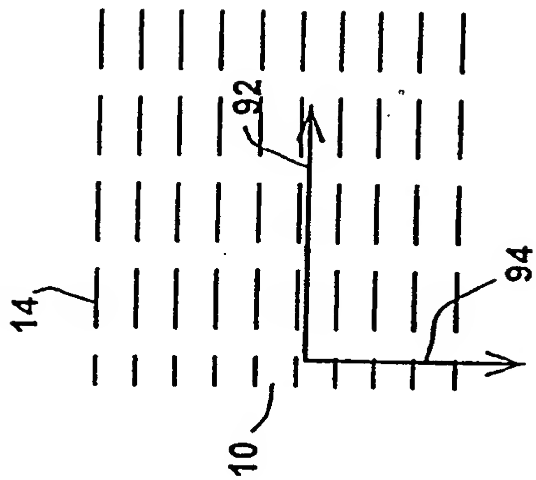


FIG. 5C



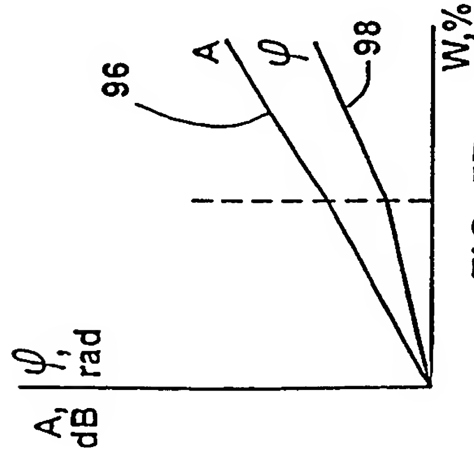


FIG. 5D

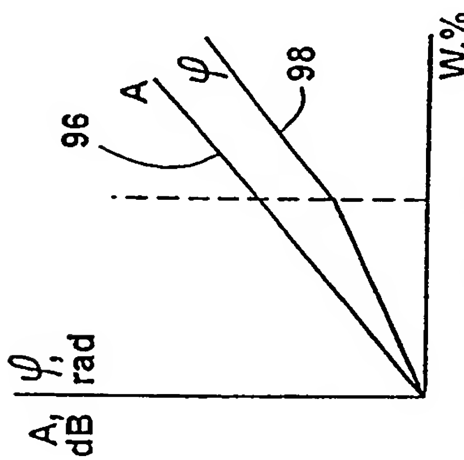


FIG. 5E

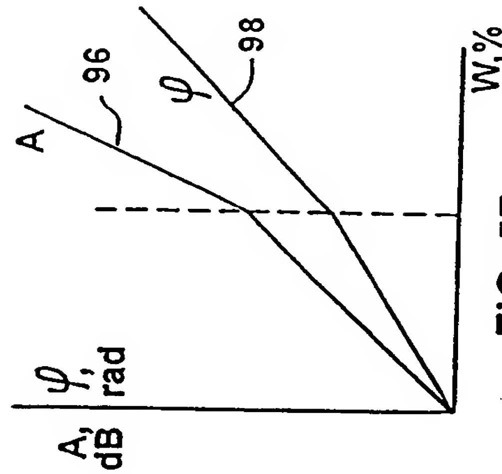


FIG. 5F

FIG. 6

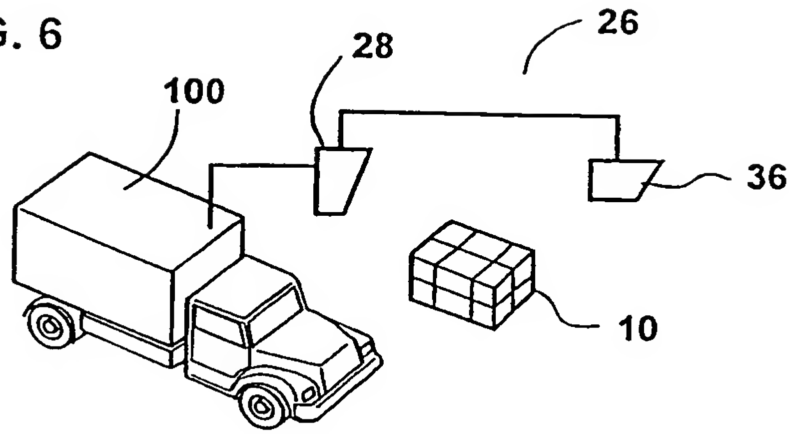
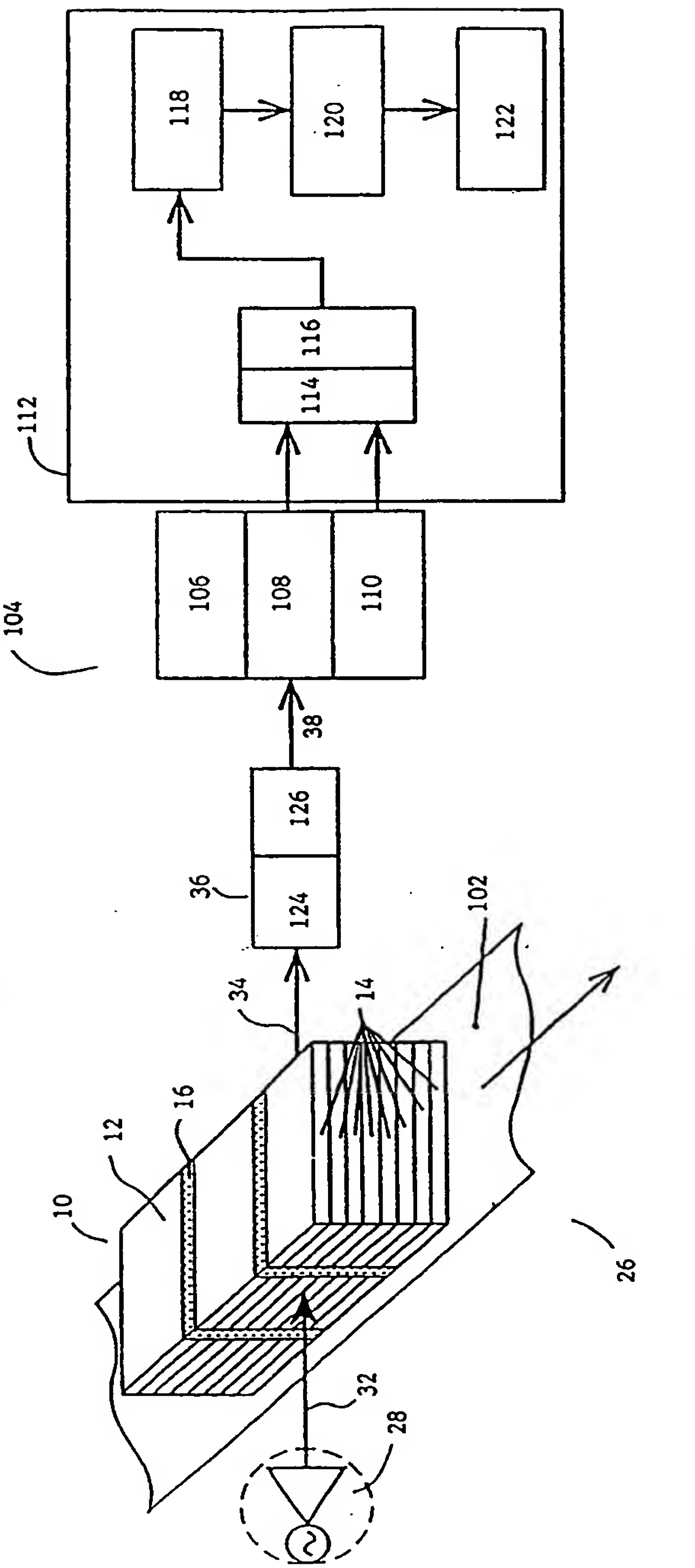


FIG. 7A


112
118
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34
14
102
16
12
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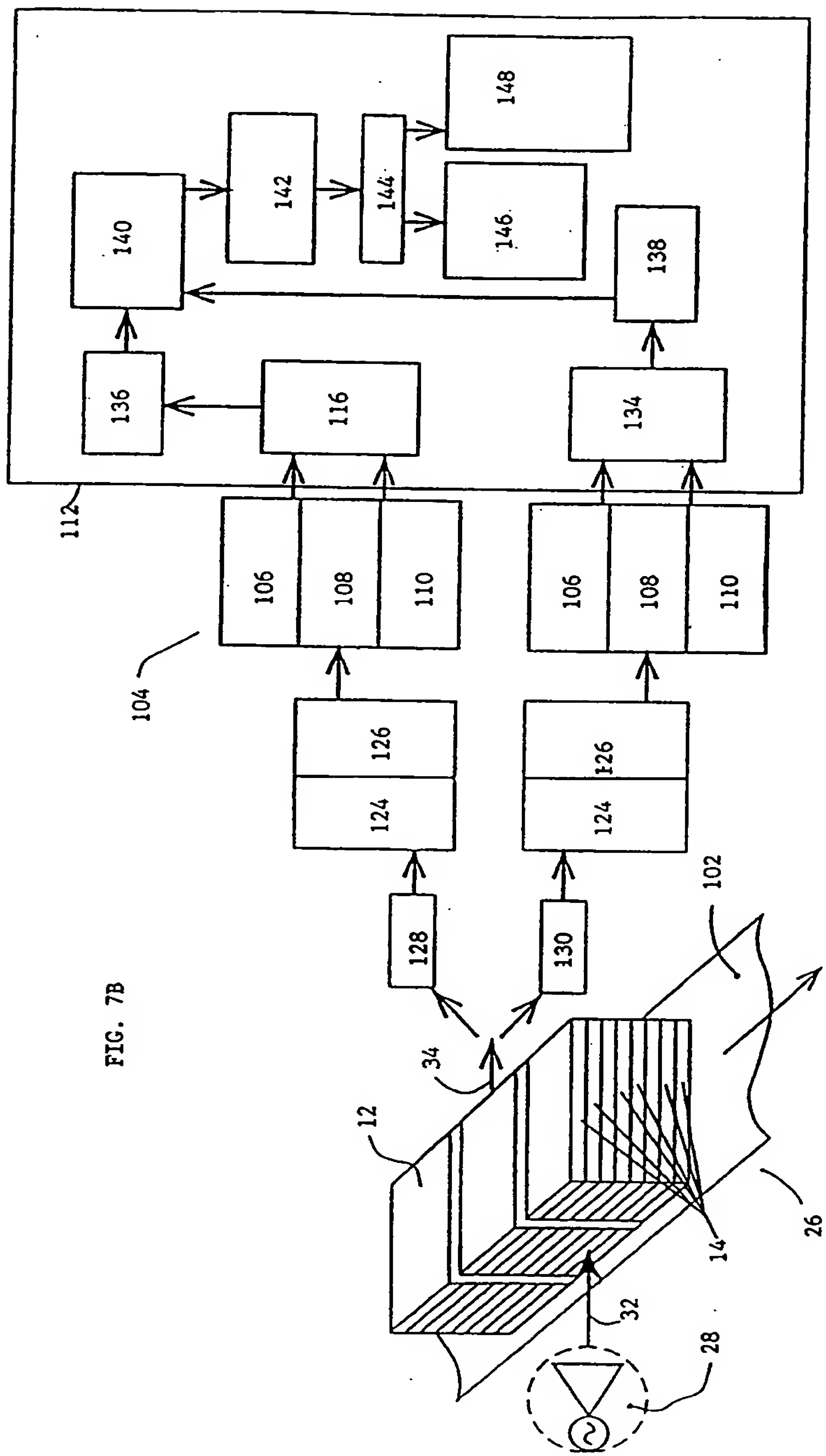
26
32
28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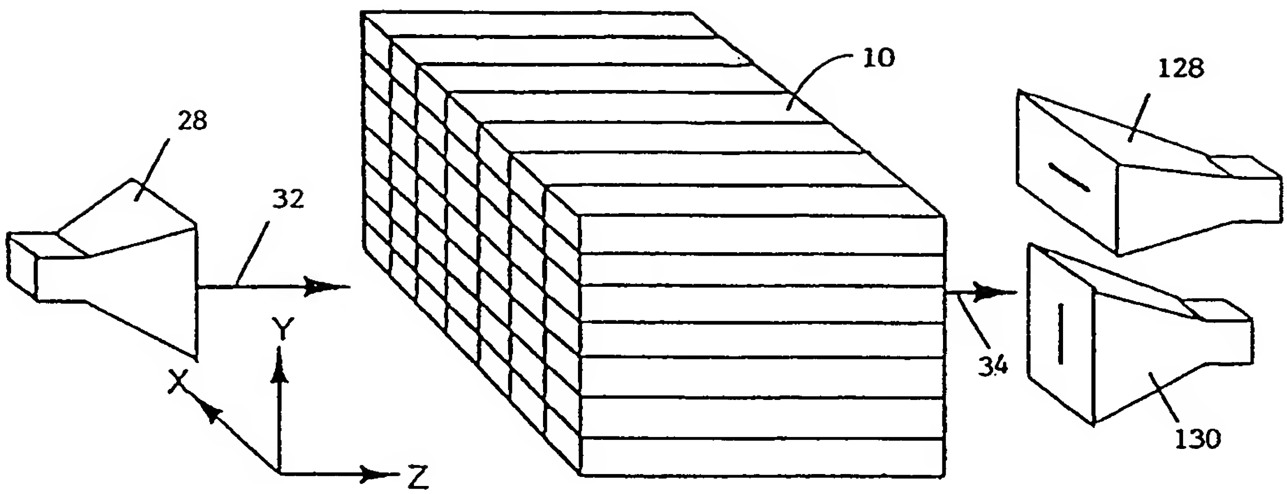
124
128
130
102
34
12
14
26
32
28

FIG. 7B

FIG. 7C



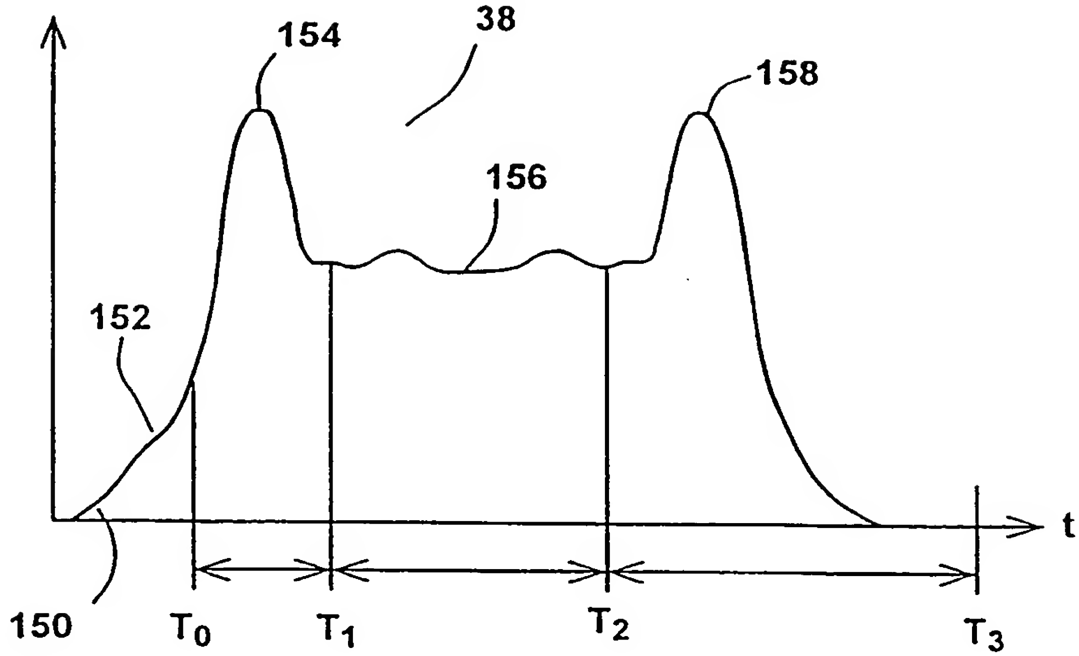


FIG. 8

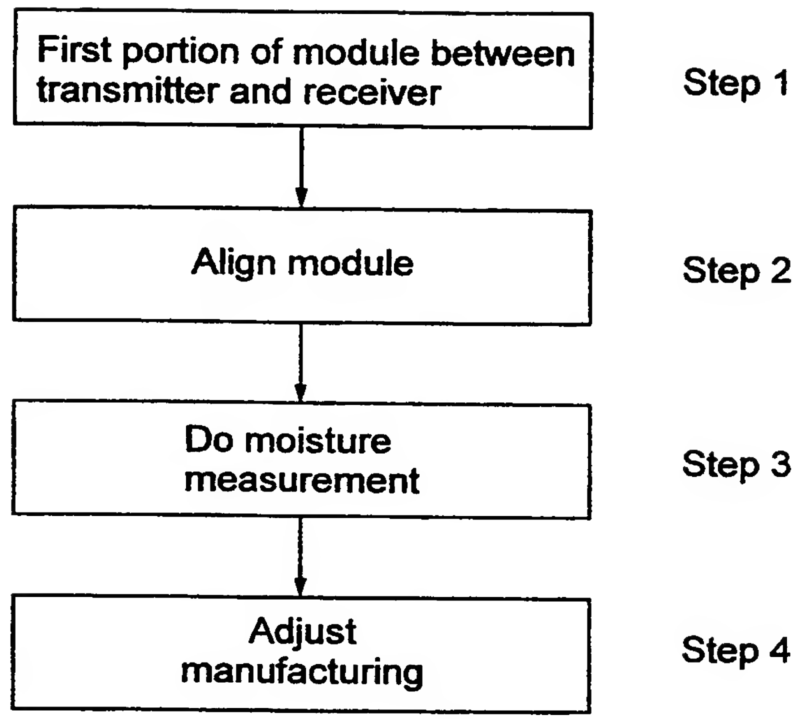

First portion of module between transmitter and receiver
Step 1
Align module
Step 2
Do moisture measurement
Step 3
Adjust manufacturing
Step 4

Fig. 9

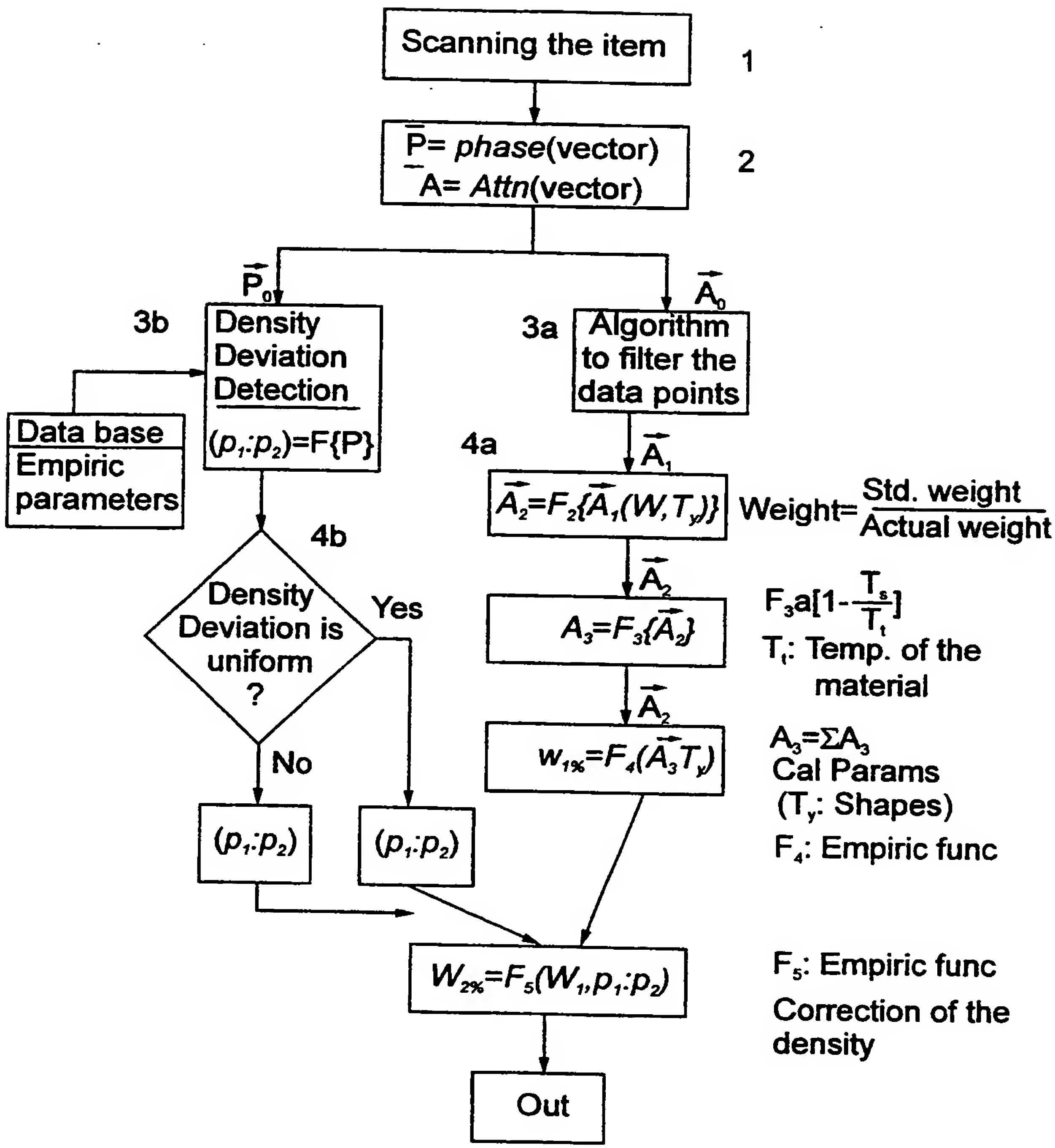

Scanning the item
1
P= phase(vector)
A= Attn(vector)
2
P0
A0
3b
Density Deviation Detection
(p1:p2)=F{P}
3a
Algorithm to filter the data points
Data base
Empiric parameters
4a
A1
A2=F2{A1(W,Ty)}
Weight=Std. weight / Actual weight
4b
Density Deviation is uniform ?
Yes
No
A2
A3=F3{A2}
F3a[1-Ts/Tt]
Tt: Temp. of the material
A2
w1%=F4(A3Ty)
A3=ΣA3
Cal Params
(Ty: Shapes)
F4: Empiric func
(p1:p2)
(p1:p2)
W2%=F5(W1,p1:p2)
F5: Empiric func
Correction of the density
Out

Fig. 10

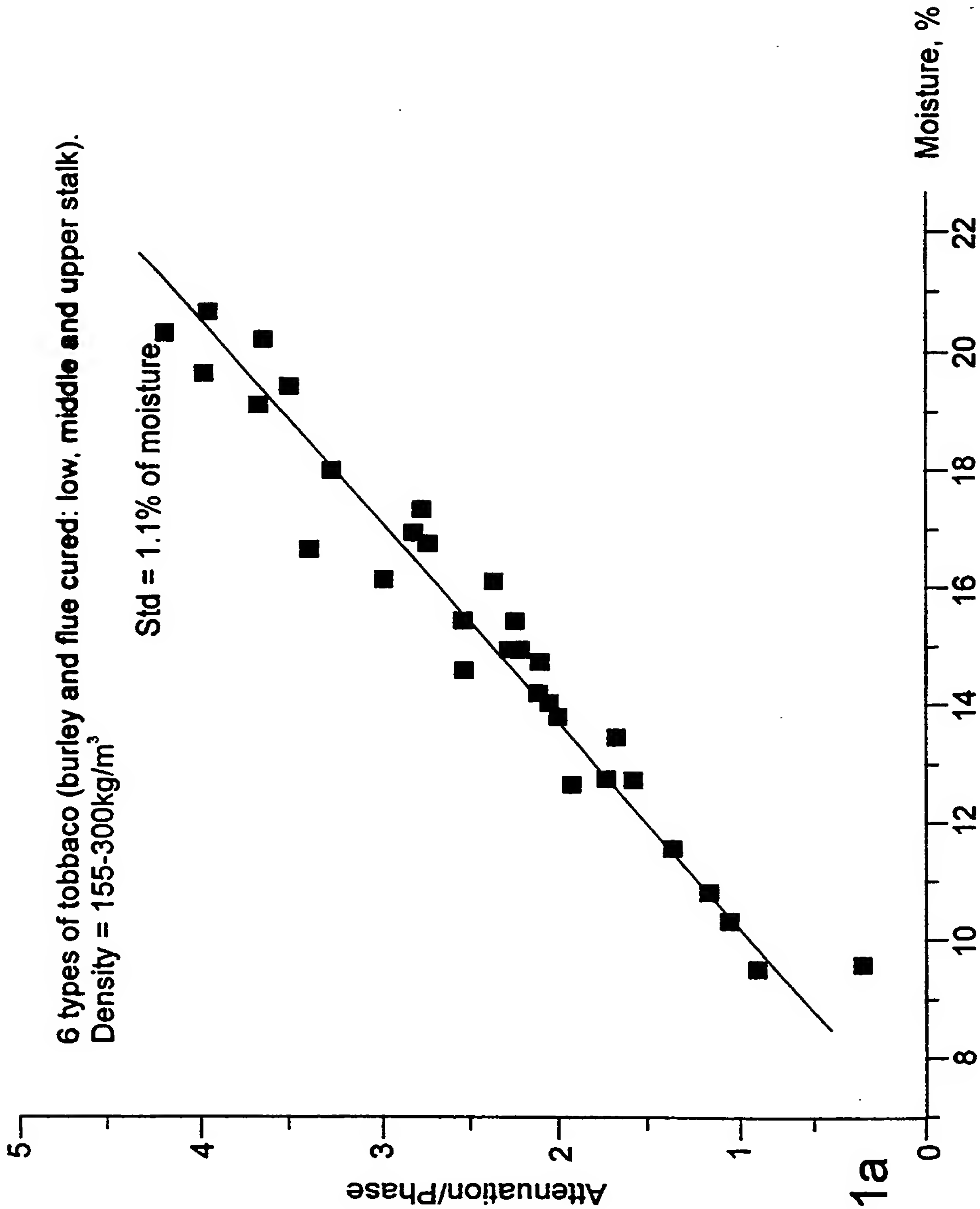

6 types of tobbaco (burley and flue cured: low, middle and upper stalk).
Density = 155-300kg/m3
Std = 1.1% of moisture
Attenuation/Phase
Moisture, %
0
1
2
3
4
5
8
10
12
14
16
18
20
22

Fig. 11a

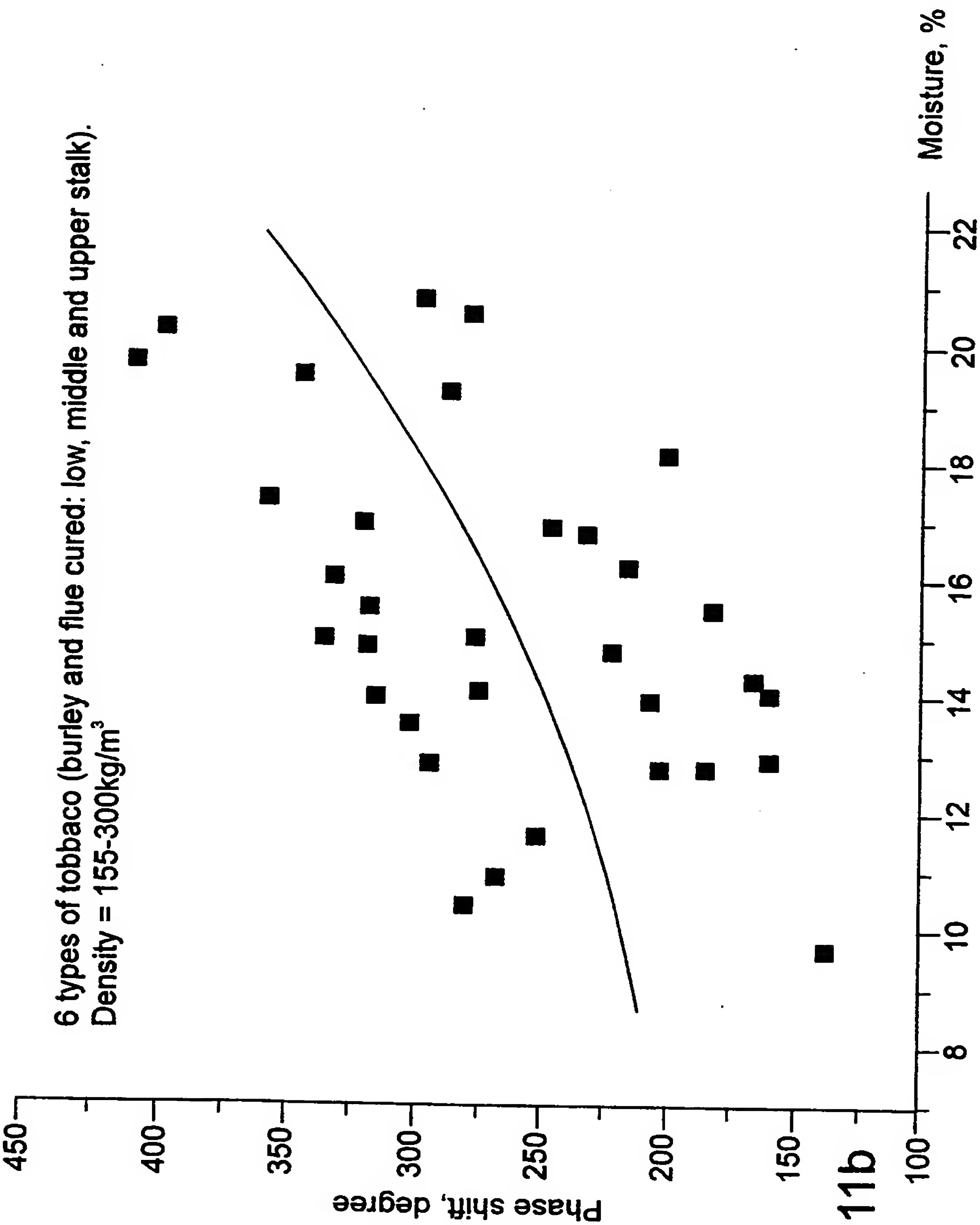

6 types of tobbaco (burley and flue cured: low, middle and upper stalk).
Density = 155-300kg/m^3
Phase shift, degree
450
400
350
300
250
200
150
100
Moisture, %
8
10
12
14
16
18
20
22

Fig. 11b

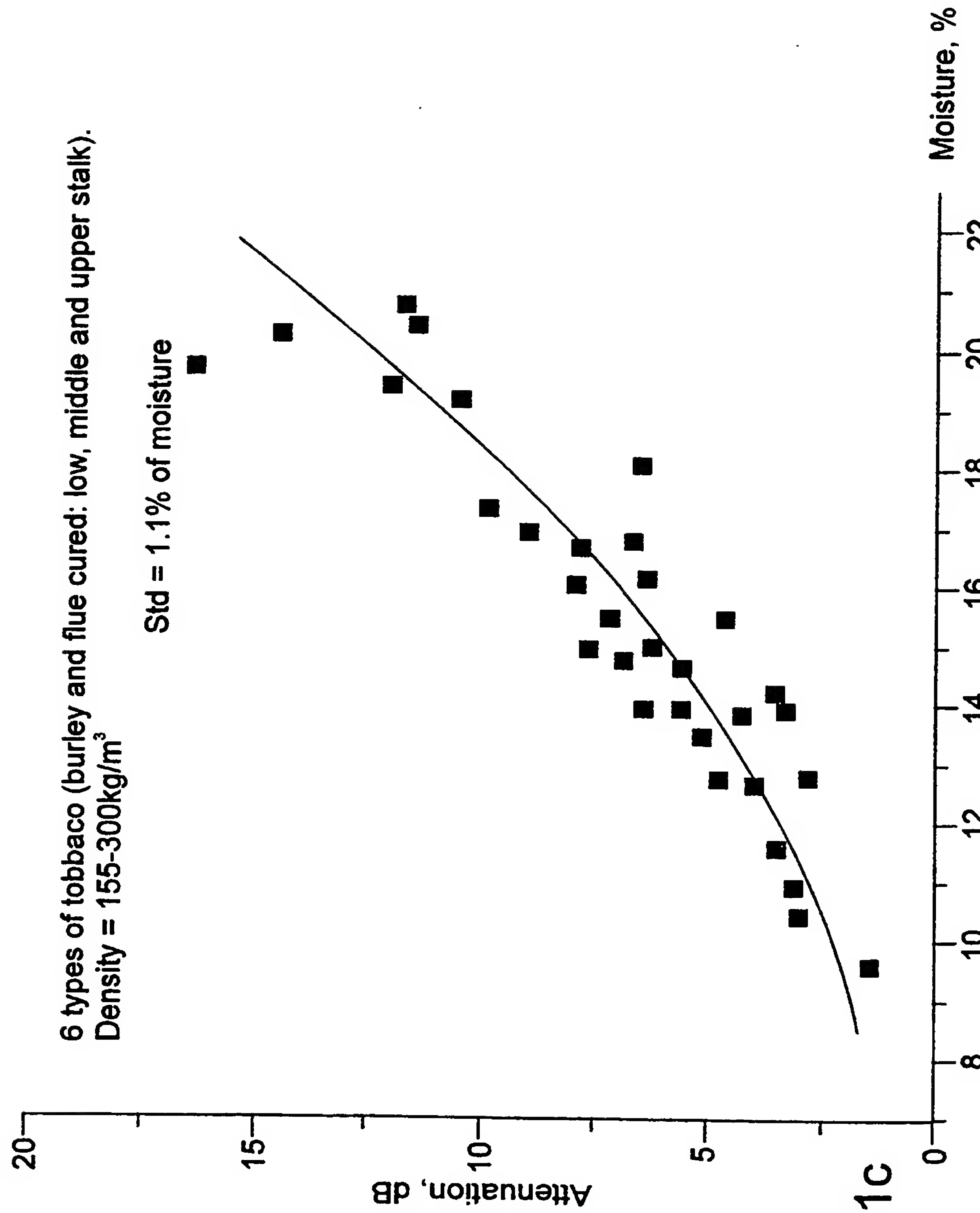

6 types of tobbaco (burley and flue cured: low, middle and upper stalk).
Density = 155-300kg/m^3
Std = 1.1% of moisture
Attenuation, dB
Moisture, %
0
5
10
15
20
8
10
12
14
16
18
20
22

Fig. 11c

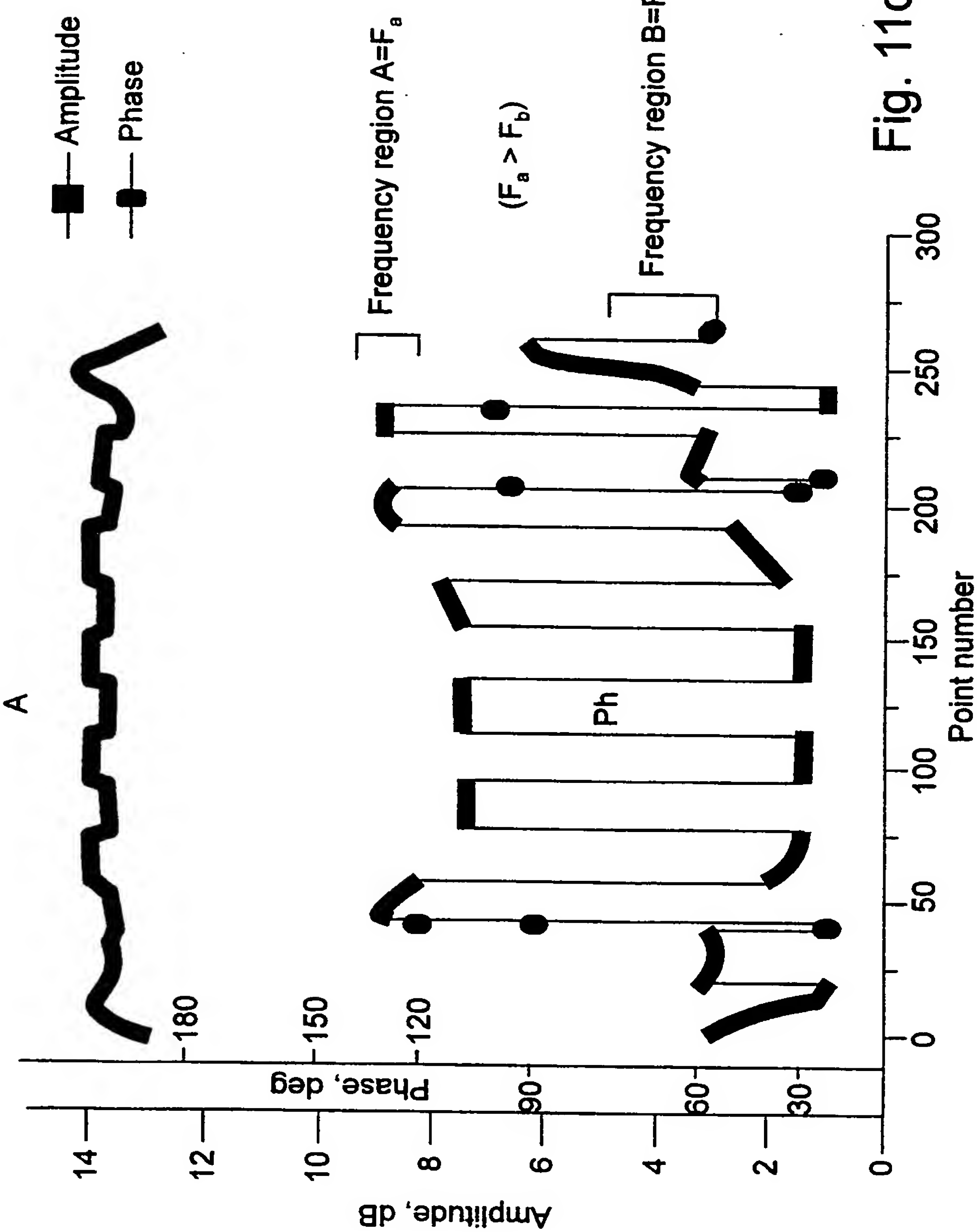

Amplitude
Phase
A
Frequency region A=F_a
($F_a > F_b$)
Frequency region B=F_b
Ph
Phase, deg
180
150
120
90
60
30
Amplitude, dB
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
Point number

Fig. 11d

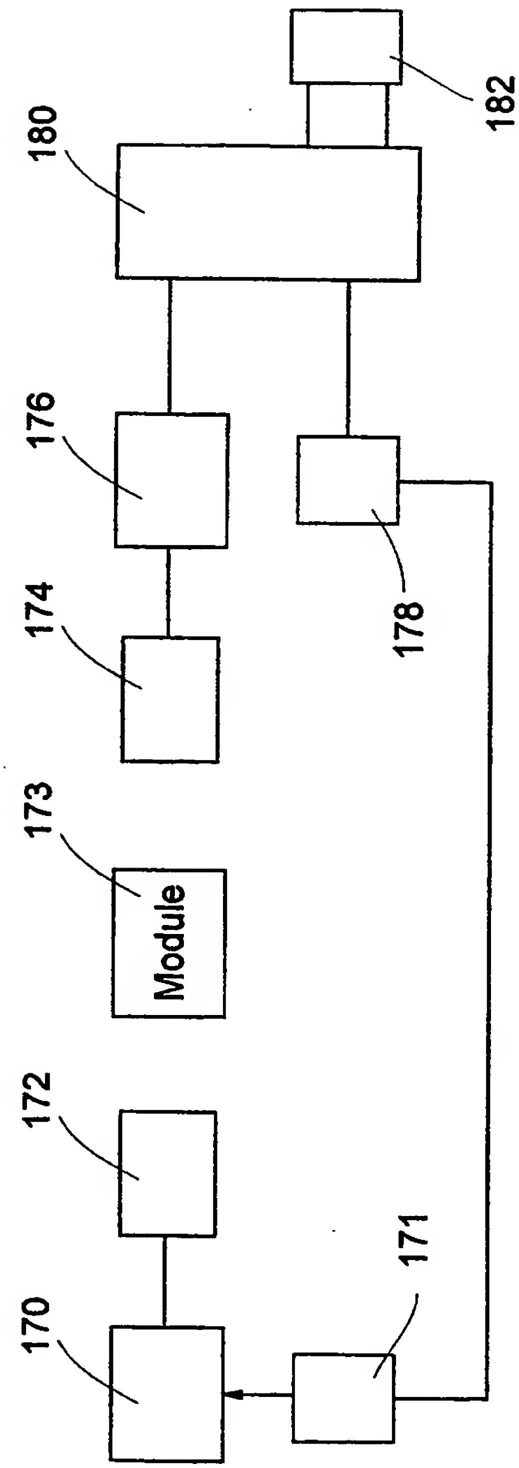
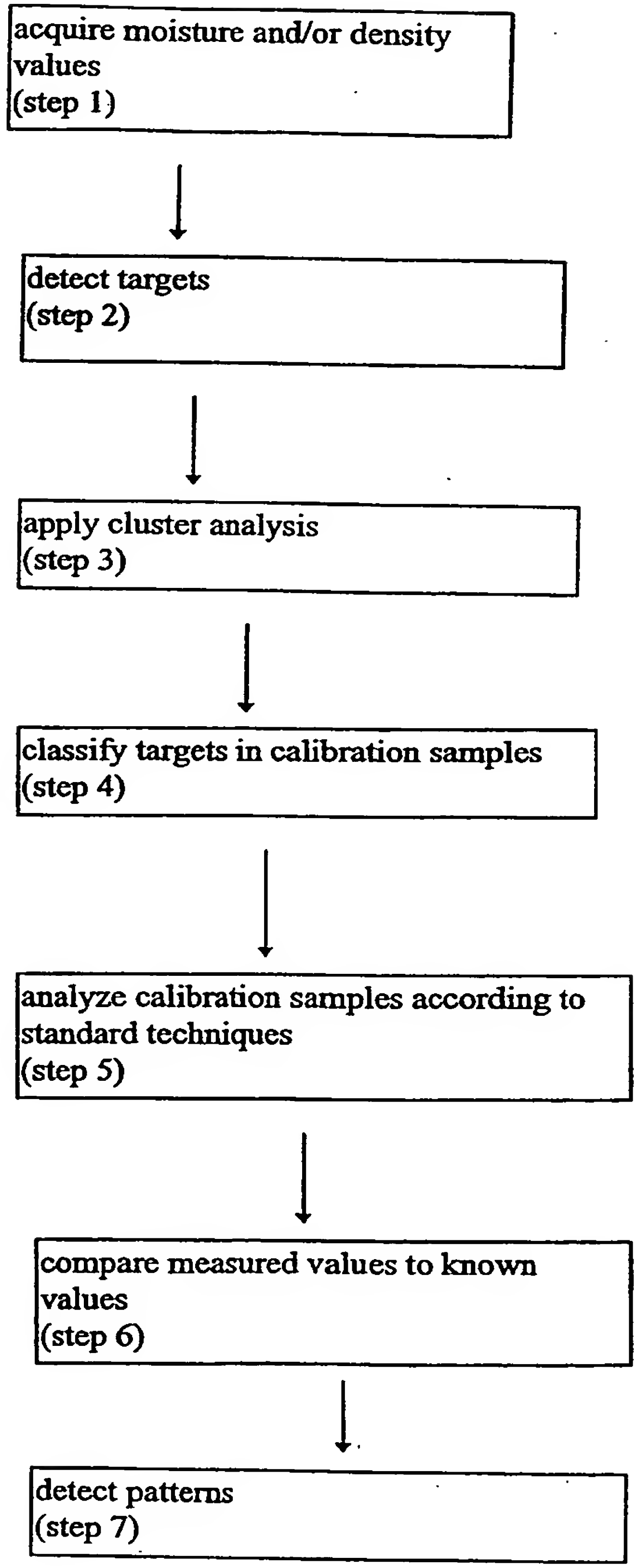


Fig. 12

Figure 13A


acquire moisture and/or density values
(step 1)
detect targets
(step 2)
apply cluster analysis
(step 3)
classify targets in calibration samples
(step 4)
analyze calibration samples according to standard techniques
(step 5)
compare measured values to known values
(step 6)
detect patterns
(step 7)

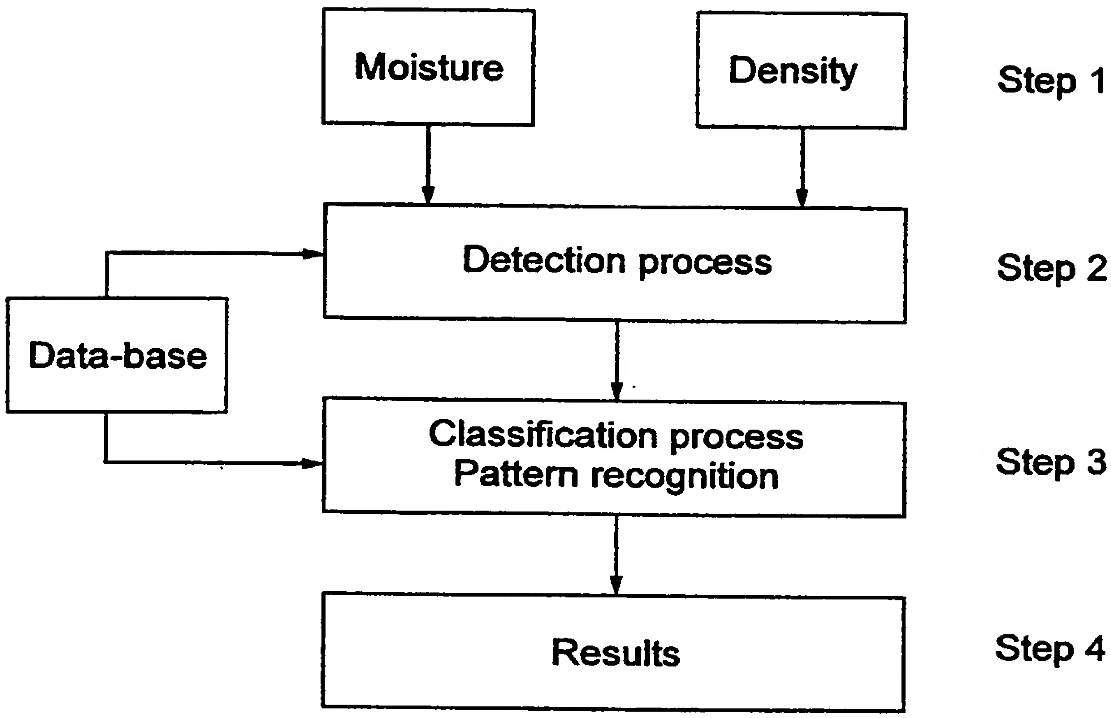

Moisture
Density
Step 1
Detection process
Step 2
Data-base
Classification process
Pattern recognition
Step 3
Results
Step 4

Fig. 13B

Classification -Pattern recognition
Per v ctor

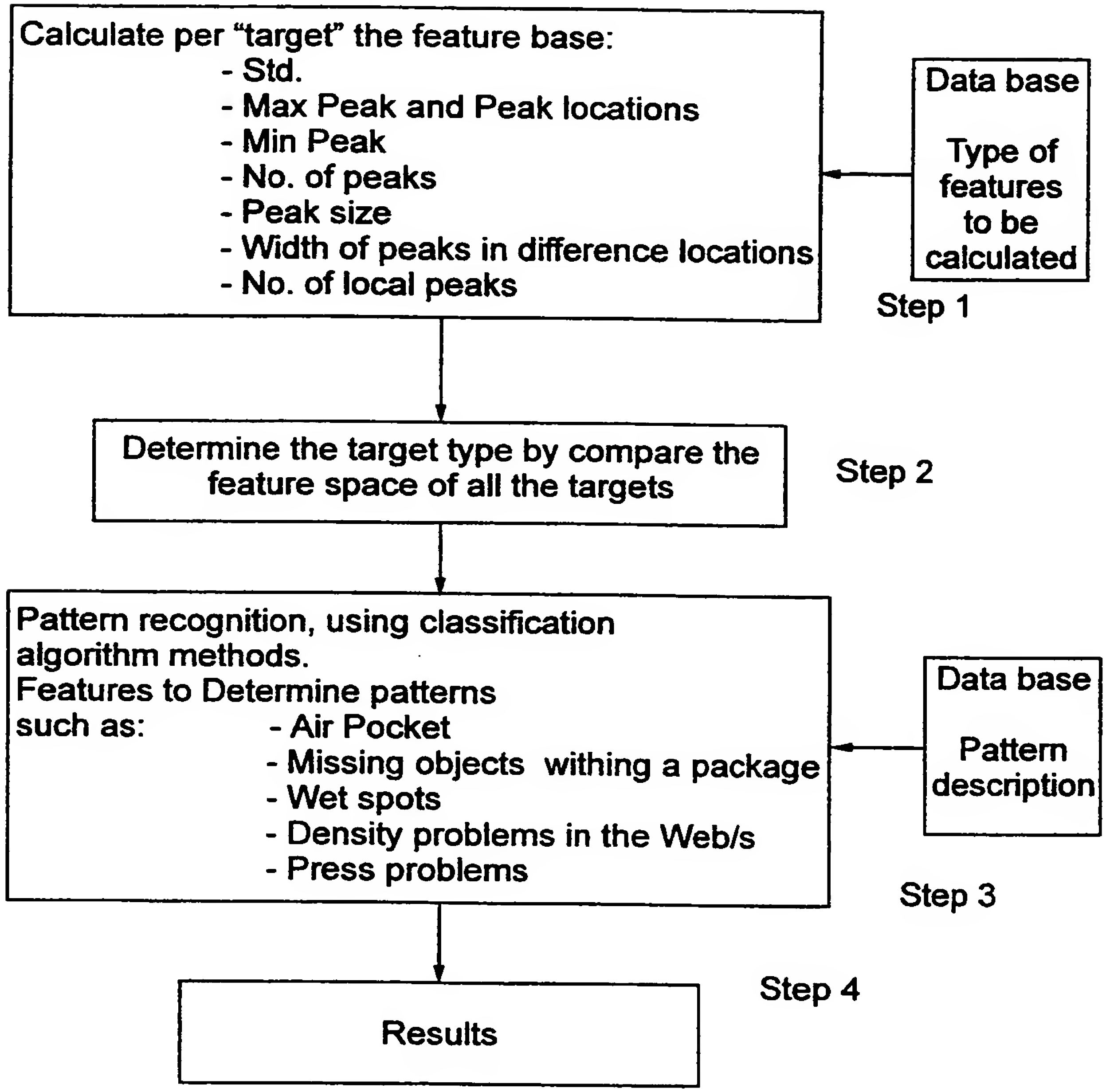


Fig. 14

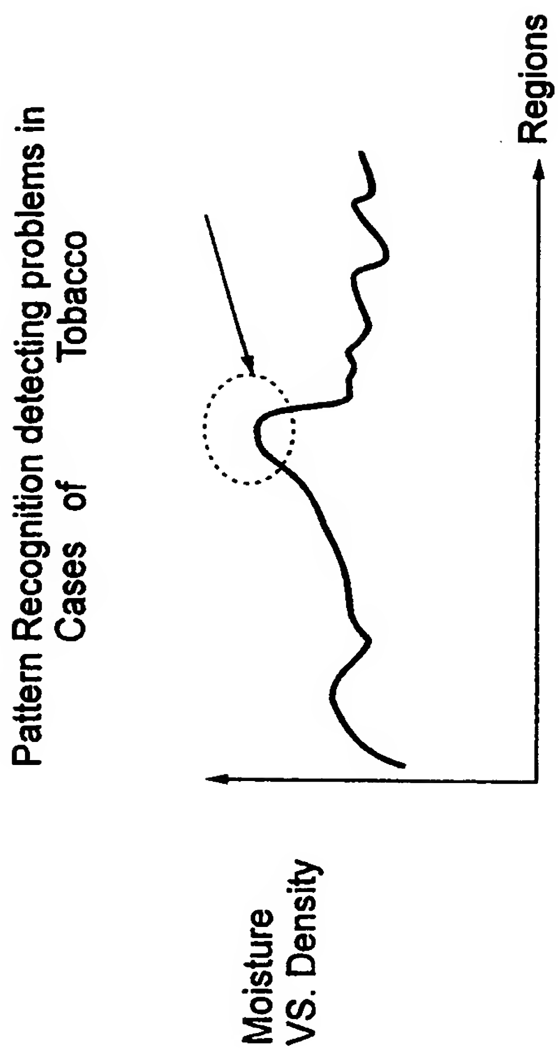

Pattern Recognition detecting problems in
Cases of Tobacco
Regions
Moisture
VS. Density

Fig. 15

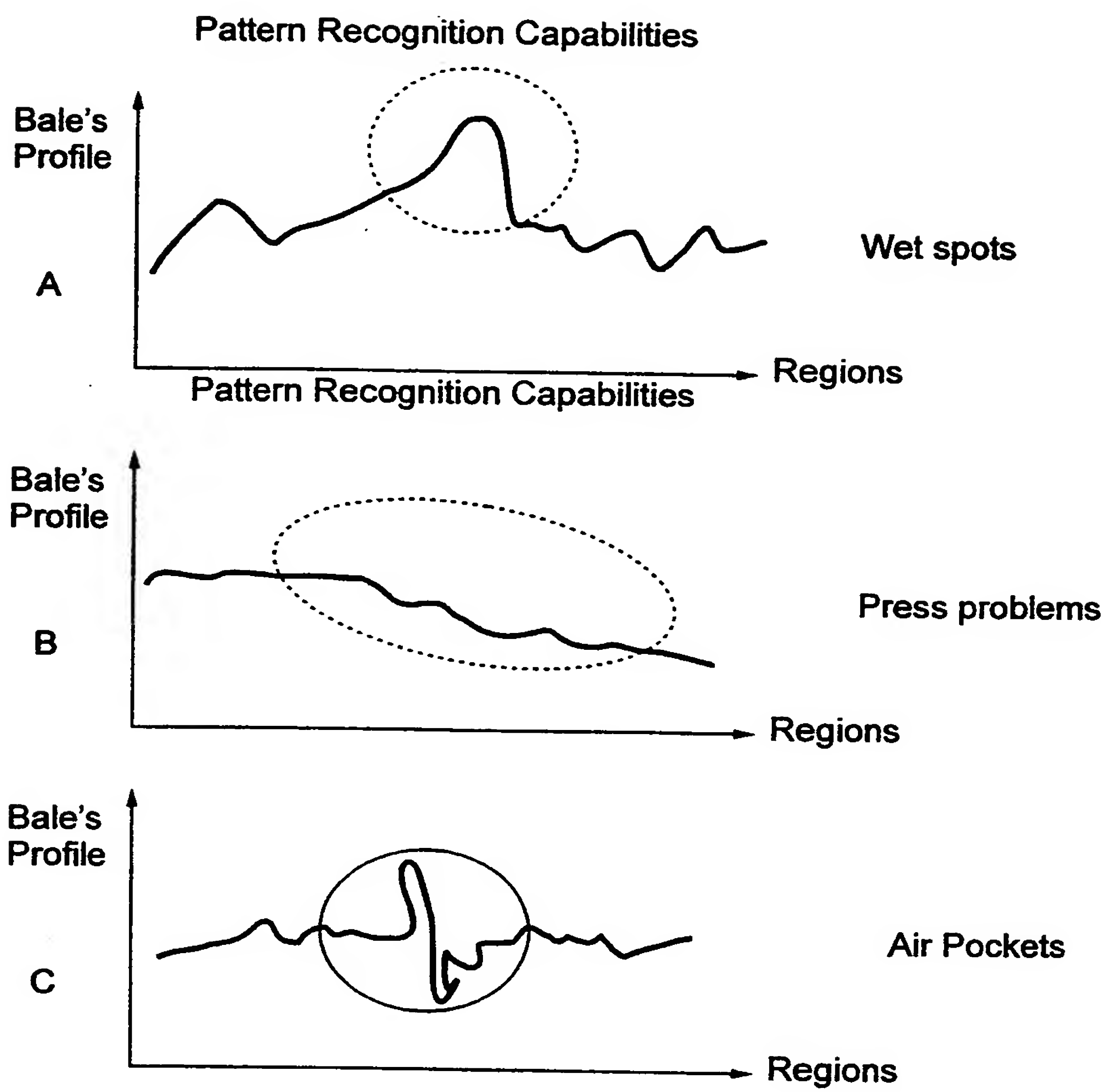
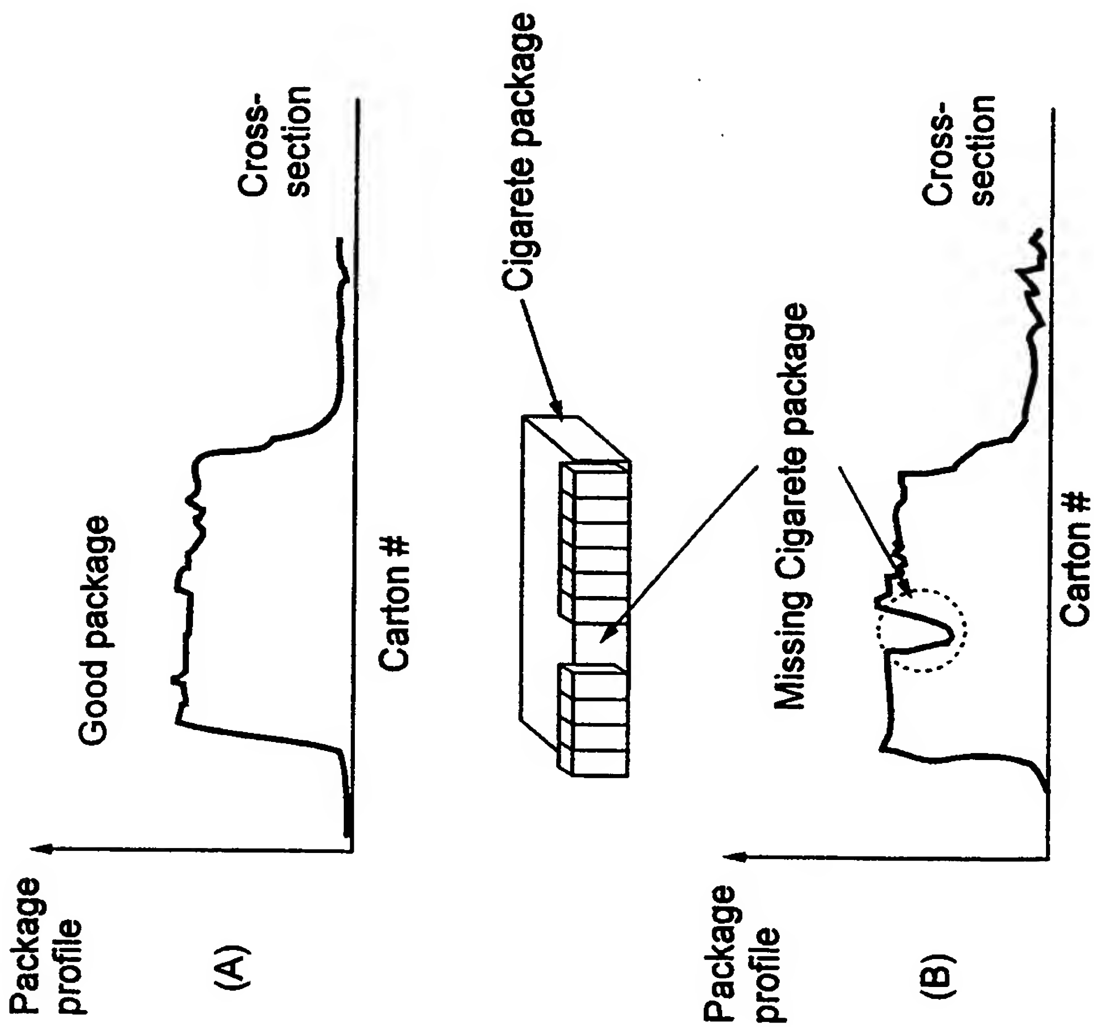

Pattern Recognition Capabilities
Bale's Profile
A
Wet spots
Regions
Pattern Recognition Capabilities
Bale's Profile
B
Press problems
Regions
Bale's Profile
C
Air Pockets
Regions

Fig. 16

Fig. 17


Package profile
(A)
Good package
Carton #
Cross-section
Cigarete package
Missing Cigarete package
Package profile
(B)
Carton #
Cross-section

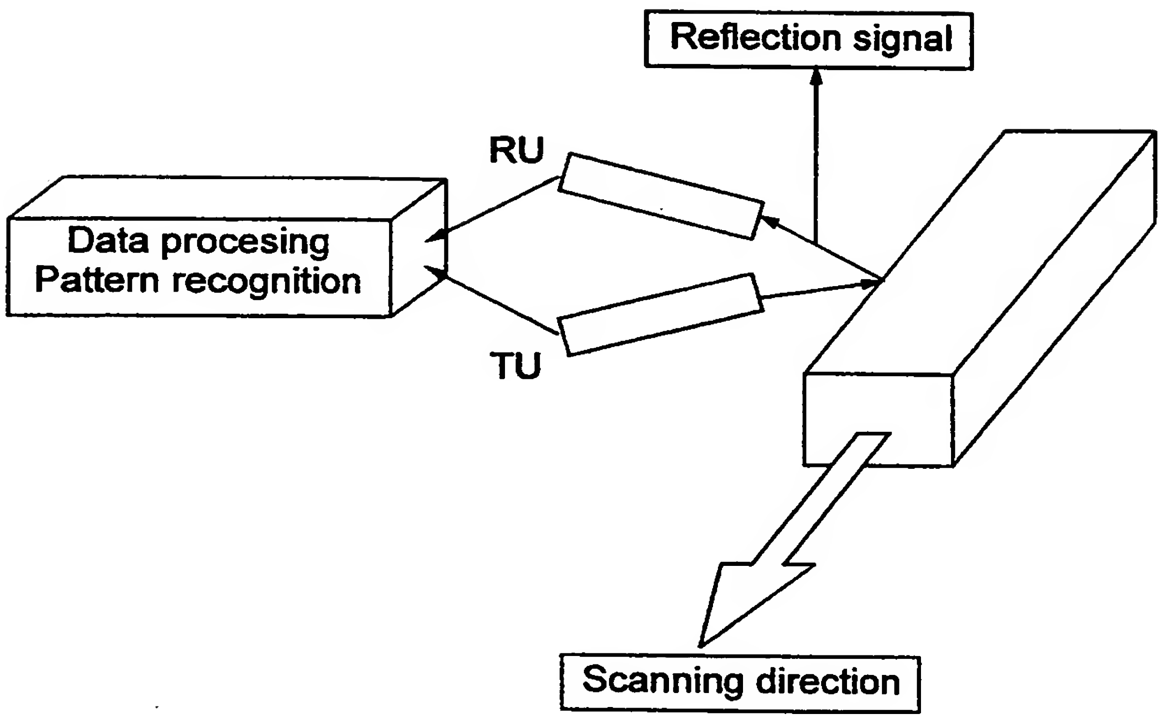

Reflection signal
RU
Data procesing
Pattern recognition
TU
Scanning direction

Fig. 18

CORRECTED VERSION*

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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(71) Applicants (*for all designated States except US*): MALCAM LTD. [IL/IL]; P.O. Box 732, 17106 Nazareth-Illit (IL). GREENVISION LTD. [IL/IL]; P.O. Box 58116, 61580 Tel Aviv (IL).

(71)(72) Applicants and Inventors: MOSHE, Danny, S. [IL/IL]; Hagilboa 11, 55024 Kiryat Ono (IL). GREENWALD, Alexander [IL/IL]; Yarden Street 9/11, 17000 Nazareth-Illit (IL). KHAZANSKI, Michael [IL/IL]; 58 Reines Street, 64587 Tel Aviv (IL).

(74) Agent: FRIEDMAN, Mark, M.; Beit Samueloff, Haomanim Street 7, 67897 Tel Aviv (IL).

(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: DEVICE AND METHOD FOR NON-INVASIVELY MEASURING AND DETERMINING MOISTURE CONTENT AND DENSITY OF LOOSE AND PACKAGED TOBACCO

(57) Abstract

A method and a device which can be used to measure the moisture content and the internal structure of material on a tobacco bale, or of a bulk volume of material such as loose tobacco leaves, by using microwave radiation. A microwave radiation source is located on one side of the tobacco, such as the tobacco bale, and an antenna is located on the opposite side of the bale. The radiation source beam is transmitted through a portion of the bale and is received by the receiving antenna, which then produces a signal. This signal is used to determine the moisture content of that portion of the bale and the mass uniformity of the bale. In addition, the methods and devices described herein can also be used to measure the moisture content of a bulk volume of loose tobacco leaves, for example as these leaves travel through a silo. Also, in a method for analyzing the internal structure of packaged tobacco, the internal structure is analyzed to detect the presence of any foreign objects or matter in packaged tobacco, as well as to confirm the presence of tobacco material throughout the package. The structural data is collected from the received and/or reflected microwaves, which are also analyzed to determine the moisture content. The raw structural data are then analyzed with detection, classification, and/or decision algorithms for analysis of the raw data. Preferably, the data analysis is based on pairs of attenuations and phase shifts obtained by passing microwaves at a plurality of frequencies through the package of tobacco which features foreign matter or objects, collectively termed "foreign components" and/or non-uniformities. This unique method enables achievement of high levels of accuracy and precision in detection and classification of the sample, in general, and of the foreign components and/or non-uniformities, in particular.

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(74) Agent: FRIEDMAN, Mark, M.; Beit Samueloff, Haomanim Street 7, 67897 Tel Aviv (IL).

(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

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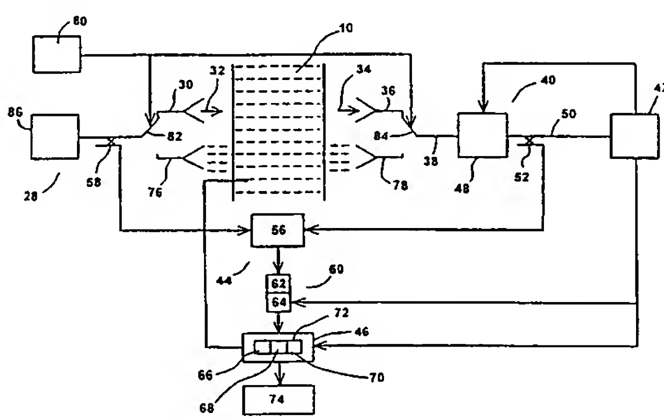
(54) Title: DEVICE AND METHOD FOR NON–INVASIVELY MEASURING AND DETERMINING MOISTURE CONTENT AND DENSITY OF LOOSE AND PACKAGED TOBACCO



(57) Abstract

A method and a device which can be used to measure the moisture content and the internal structure of material on a tobacco bale (12), or of a bulk volume of material such as loose tobacco leaves (14), by using microwave radiation. A microwave radiation source (28) is located on one side of the tobacco, such as the tobacco bale, and an antenna (30) is located on the opposite side of the bale. The radiation source beam (32) is transmitted through a portion of the bale and is received by the receiving antenna (36), which then produces a signal (38). This signal is used to determine the moisture content of that portion of the bale and the mass uniformity of the bale. In addition, the methods and devices described herein can also be used to measure the moisture content of a bulk volume of loose tobacco leaves, for example as these leaves travel through a silo. Also, in a method for analyzing the internal structure of packaged tobacco, the internal structure is analyzed to detect the presence of any foreign objects or matter in packaged tobacco, as well as to confirm the presence of tobacco material throughout the package. The structural data is collected from the received and/or reflected microwaves, which are also analyzed to determine the moisture content. The raw structural data are then analyzed with detection, classification, and/or decision algorithms for analysis of the raw data. Preferably, the data analysis is based on pairs of attenuations (42) and phase shifts (44) obtained by passing microwaves at a plurality of frequencies through the package of tobacco which features foreign matter or objects, collectively termed "foreign components" and/or non-uniformities. This unique method enables achievement of high levels of accuracy and precision in detection and classification of the sample, in general, and of the foreign components and/or non-uniformities, in particular.

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GA	Gabon
GB	United Kingdom
GE	Georgia
GH	Ghana
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IL	Israel
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgyzstan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakstan
LC	Saint Lucia
LI	Liechtenstein
LK	Sri Lanka
LR	Liberia
LS	Lesotho
LT	Lithuania
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
MK	The former Yugoslav Republic of Macedonia
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
MX	Mexico
NE	Niger
NL	Netherlands
NO	Norway
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PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SN	Senegal
SZ	Swaziland
TD	Chad
TG	Togo
TJ	Tajikistan
TM	Turkmenistan
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US	United States of America
UZ	Uzbekistan
VN	Viet Nam
YU	Yugoslavia
ZW	Zimbabwe

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL99/00421

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) : G01R 27/04
US CL : 324/640
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 324/632, 637, 638, 639, 694; 73/73;

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,845,529 A (MOSHE et al) 08 December 1998 (08.12.1998), entire document.	1-29
Y	US 5,619,143 A (STEVENS et al) 08 April 1997 (08.04.1997), entire document.	1-29
Y	US 4,475,080 A (WALKER) 02 October 1984 (02.10.1984), entire document.	1-29
Y	US 5,621,330 A (GREENWALD et al) 15 April 1997 (15.04.1997), entire document.	1-29
A	US 4,675,595 A (HANE) June 23 1987 (23.06. 1987), entirte docuument.	1-29

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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Date of the actual completion of the international search

Date of mailing of the international search report
17 JUL 2000

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